Michigan State University

ECE 480 DESIGN TEAM 6

Automated Inspection Device for Electric Fan Clutch Actuators

For BorgWarner, Inc.

Jacob H. Co

Joshua S. DuBois

Stephen J. Sutara

Codie T. Wilson

Dr. Virginia M. Ayres – Facilitator

Final Report

Friday, May 1st, 2009

BorgWarner

Executive Summary

The inspection of fan clutch actuators is vital in ensuring the proper operation of radiator cooling fans in automobiles. The current inspection method employed by BorgWarner, Inc. is manually-driven: each inspection task requires a different connection to the actuator, and its measurement result is recorded by hand. In the spring of 2009, BorgWarner tasked ECE 480 Design Team 6 with the design of an automated inspection device to replace their manual inspection method.

The team has successfully developed a device that automatically performs inspection tasks. The device interfaces with the fan clutch actuator using a single connection, and inspection is run through software on any USB-enabled PC. The measurement results are automatically gathered, and are printed out for present validation, as well as stored in a database for comparison. This solution streamlines the inspection process, increasing efficiency and eliminating human error. As a result, possible defects can be identified faster, and more robust fan clutch actuators can be designed.

Acknowledgements

ECE 480 Design Team 6 would like to thank the following people for their help in developing Automated Actuator Inspection Device:

- **BorgWarner: Stephen Bohan, Jim Ignatovich and Al Dove**

  for their background and guidance on fan clutch actuators and inspection

- **MSU ECE Technical Services: Brian Wright, Gregg Mulder and Roxanne Peacock**

  for their support in procuring and fabricating necessary components

- **MSU College of Engineering: Dr. Virginia Ayres and Dr. Erik Goodman**

  for their support and guidance throughout the design process

Table of Contents

1. Introduction and Background

1.1. Introduction

The fan clutch actuator is responsible for engaging the radiator cooling fan in automobiles, which maintains or lowers the engine coolant fluid temperature inside the radiator. Mechanical fan clutch actuators exist as bi-metallic coils that contract when hot and expand when cold, and in turn, engage or disengage the radiator cooling fan. BorgWarner, Inc., in partnership with ECE 480 Design Team 9 in the fall of 2007, has developed an electric fan clutch actuator that uses an electronic temperature sensor in place of the mechanical relay. Electric actuators have a significant advantage over their mechanical counterparts in obtaining more accurate temperature readings, therefore being able to engage or disengage the radiator cooling fan faster, as well as run the fan at speeds commensurate to the temperature.

However, electric actuators also have a greater design complexity than mechanical actuators, and require more stringent inspection methods to verify proper operation. BorgWarner's current inspection method for their electric fan clutch actuators is a manual process. Isolated circuit metering systems are manually used to retrieve voltage, current, resistance and capacitance measurements. These measurements are manually recorded on a system requirements sheet.

In the spring of 2009, ECE 480 Design Team 6 developed an automated inspection device for BorgWarner's electric fan clutch actuators. The device interfaces with a PC through a USB connection, and automatically takes required voltage, current, resistance and capacitance measurements for actuator units under test. The measurements are stored in a database for later lookup and comparison, as well as on a hardcopy printout similar to the system requirements sheets currently used under the manual inspection method. The Automated Actuator Inspection Device significantly increases inspection efficiency and actuator design efforts in comparison to its manual counterpart.

1.2. Background
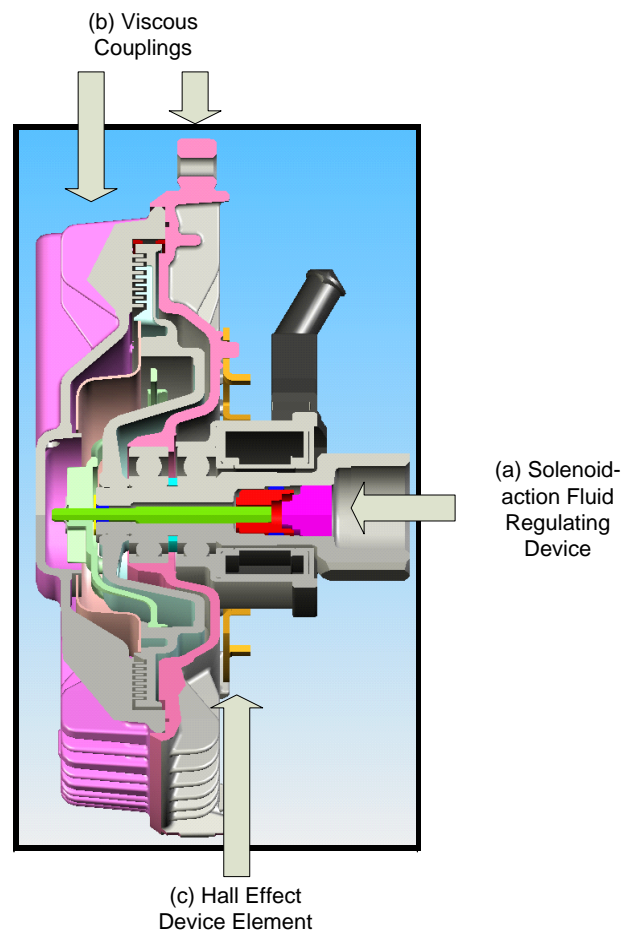
Figure 1.2.1. BorgWarner Generation II Actuator Subassembly

A cross-sectional view of BorgWarner's Generation II electric fan clutch actuator system is shown in Figure 1.2.1. The actuator system consists of an electronic temperature sensor, solenoid-action fluid regulating device, and a Hall Effect device. The electronic temperature sensor monitors the temperature of the engine coolant fluid, determining the engaging and disengaging of the radiator cooling fan. The solenoid-action fluid regulating device, shown in (a) in Figure 1.2.1, is controlled by a variable current that proportionally regulates the amount of viscous fluid released into the clutch couplings, shown in (b) in Figure 1.2.1, which solidifies under heat and links the couplings together to rotate the fan.

The edge-sensing Hall Effect device monitors the speed of the radiator cooling fan through the number of passes of the Hall element, shown in (c) in Figure 1.2.1, and regulates the speed in accordance with the desired engine coolant fluid temperature. A general electrical schematic of the electric fan clutch actuator is shown in Figure 1.2.2.
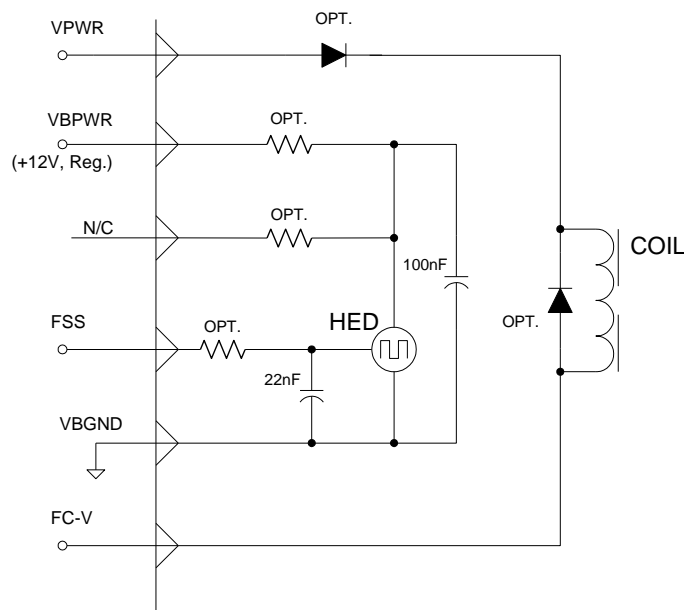
Figure 1.2.2. BorgWarner Generation II Actuator Electrical Schematic [1]

As these devices are vital in the proper operation of the radiator cooling fan – and in turn, the automobile as a whole – stringent inspection methods are required to ensure their correct functioning. BorgWarner's current inspection method is a manual measurement of voltages, currents, resistances and capacitances through a device containing off-the-shelf metering systems. This method involves multiple connections and the hand-recording of measurements. While this is suitable for validation, a more unified and automated method is desired.

2. Solution Space and Specific Approach

2.1. Design Specifications and Objectives

In designing the Automated Actuator Inspector, the following design specifications must be followed:

- **Measurements:** Voltage, current, resistance and capacitance measurements as listed on system requirements sheets for BorgWarner, Inc. Generation I and Generation II actuators

- **Statistics:** Coil current time plot, speed pulse rise and fall time, speed sensor pulse time plot, speed pulse edge-to-edge time, coil magnetic field, mechanical travel (linear and angular) versus coil current

In addition, the following design objectives must be met:

- **Automation:** Automated measuring and storage process

- **Accuracy:** Accurate voltage/current/resistance/capacitance measurements in mV/μA/1Ω/nF scales, respectively

- **Expandability:** Future measurement additions

- **Storage:** Sufficient database and hardcopy processing

- **Safety:** Short circuits, protection during speed sensor testing

- **Cost:** Reasonable total device cost

- **Size:** Workbench-fitting footprint

- **Power:** Efficient power consumption

2.2. FAST Diagram
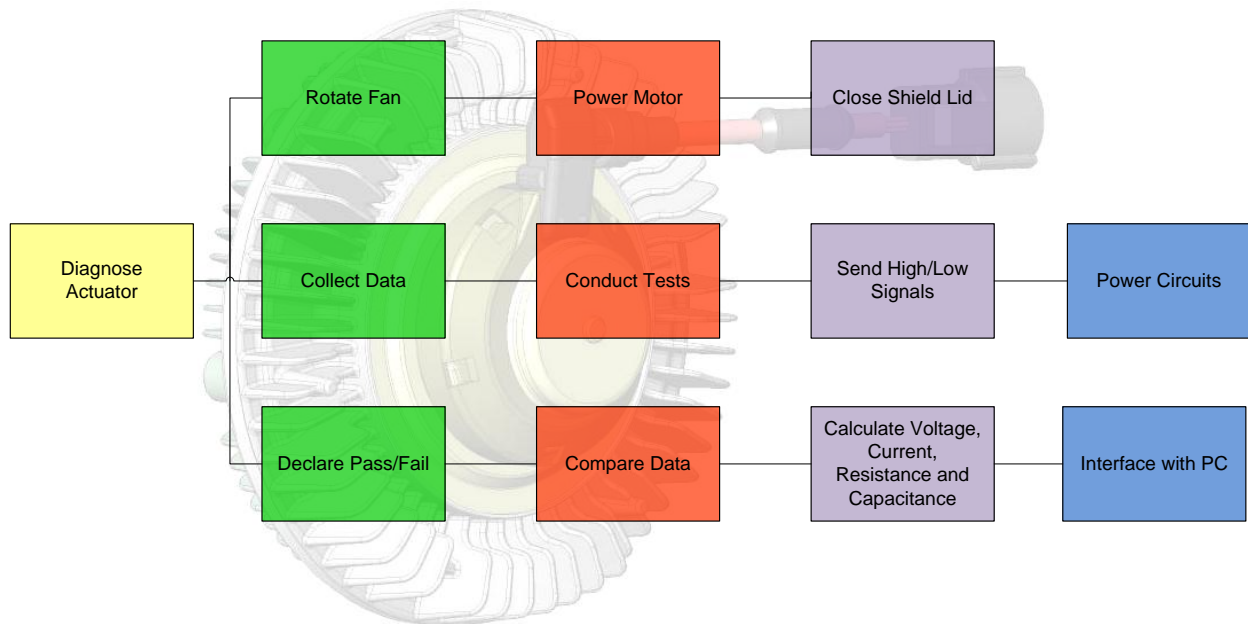
Figure 2.2.1. Automated Actuator Inspection Device FAST Diagram

The Function Analysis System Technique (FAST) Diagram for the Automated Actuator Inspection Device is shown in Figure 2.2.1. It organizes the purpose, objectives and functions of the device. In order to diagnose a fan clutch actuator, data must be collected about it. This is done by conducting various tests. The tests are enabled and disabled through high and low signals sent by powered switching circuits. In addition, the fan clutch must be rotated to simulate operation. This is achieved through the powering of a motor attached to the clutch. However, a safety switch only allows power to be delivered to the motor if the lid of the device is closed. From there, a pass or fail declaration is made by comparing calculated voltage, current, resistance and capacitance measurements to the functional requirements of the actuator. This comparison and calculation is done through a PC interface.

2.3. House of Quality/Critical Customer Requirements
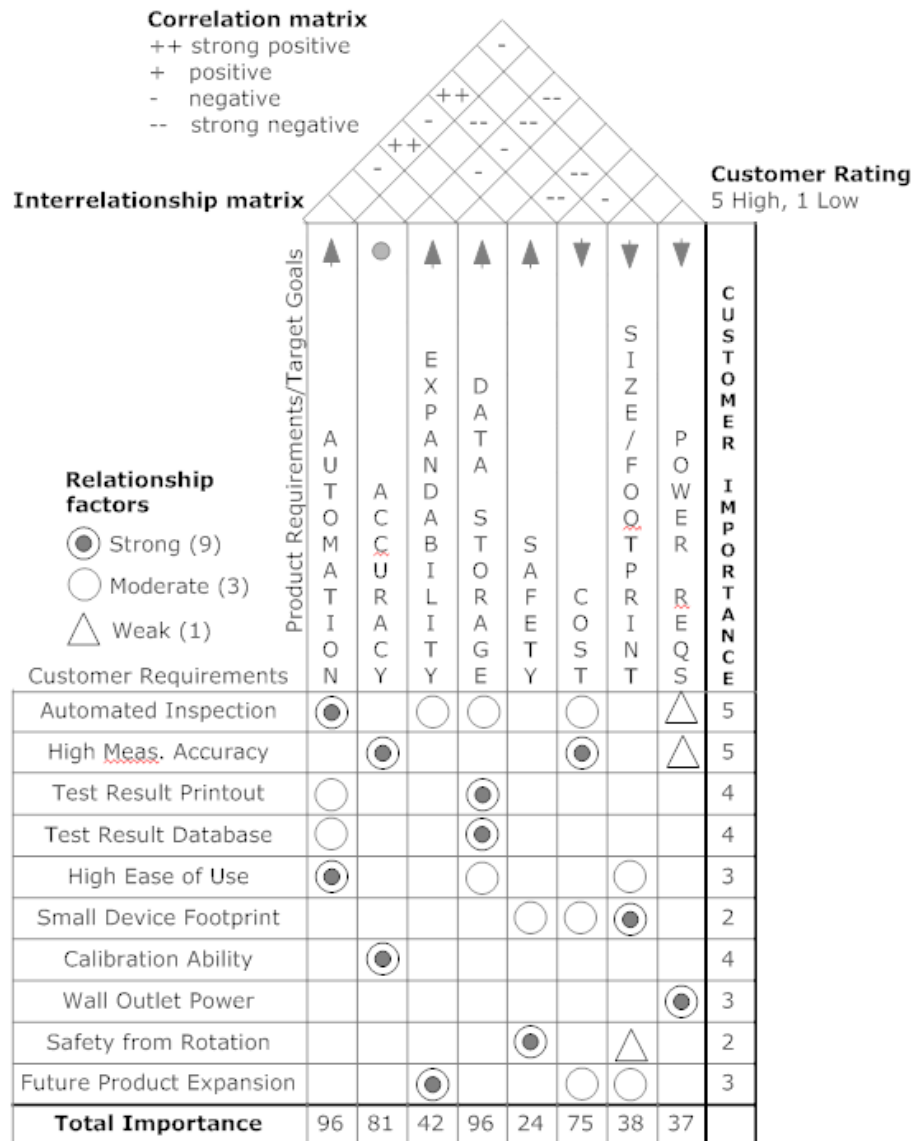
Figure 2.3.1. Automated Actuator Inspection Device House of Quality

The House of Quality for the Automated Actuator Inspection Device is shown in Figure 2.3.1. As a part of Quality Function Deployment (QFD), the House of Quality defines the relationship between Critical Customer Requirements (CCRs) and engineering design objectives. ECE 480 Design Team 6 kept automation, accuracy, data storage and cost as objectives of high importance in the design of the Automated Actuator Inspection Device, as seen in the House of Quality total importance weighting.

2.4. Conceptual Design Descriptions

Listed are ECE 480 Design Team 6's initial conceptual designs for the Automated Actuator Inspection Device:

2.4.1. Commercial Meter Interfacing

The commercial meter interfacing design improves upon BorgWarner's manual inspection method. The PC interfaces with metering systems purchased off-the-shelf, which are directly attached to the electric fan clutch actuator. The PC stores the metering systems' measurements in a database, as well as on a hardcopy printout. This ensures the measurement accuracy given by professionally-developed metering systems. However, the cost in purchasing these metering systems is high. Interfacing with the metering systems may also prove to be difficult if the user does not have a USB or GPIB mode control and measurement output.

2.4.2. Data Acquisition and Processing

The data acquisition and processing design emulates the functionality of metering systems by utilizing the PC to perform calculations. Preconditioning circuits designed by ECE 480 Design Team 6 transforms and scale raw data signals from the electric fan clutch actuator into measurable waveforms. These waveforms are communicated to the PC through USB using a data acquisition module, from which calculations are made to derive voltage, current, resistance and capacitance measurements. The cost of this design is relatively inexpensive, in designing metering circuitry in-house. However, accuracy may prove to be an issue for the same reason. Additionally, upgrading the system to take on new sets of measurements following the tenure of ECE 480 Design Team 6 may be problematic.

2.5. Feasibility Matrix

Design Criteria	Weight	Commercial Meter Interfacing	Data Acquisition and Processing
Automation	5	5	5
Accuracy	5	5	3
Expandability	4	3	2
Data Storage	4	5	5
Safety	4	4	3
Cost	3	1	5
Size/Footprint	3	2	5
Power Requirements	3	2	4
TOTALS		113	122

Table 2.5.1. Conceptual Design Feasibility Matrix

Table 2.5.1 shows the rankings of ECE 480 Design Team 6's initial conceptual designs through a feasibility matrix. The design criteria are given weights based on an importance scale of 1-5, with 1 being slightly important and 5 being extremely important. The initial conceptual designs are given rankings based on an effectiveness scale of 1-5, with 1 being slightly effective and 5 being extremely effective in fulfilling the design criteria.

Based on effectiveness totals, the team continued with the data acquisition and processing design. Considerations from the commercial meter interfacing design, as well as from other ideas, were taken into account throughout the design process.

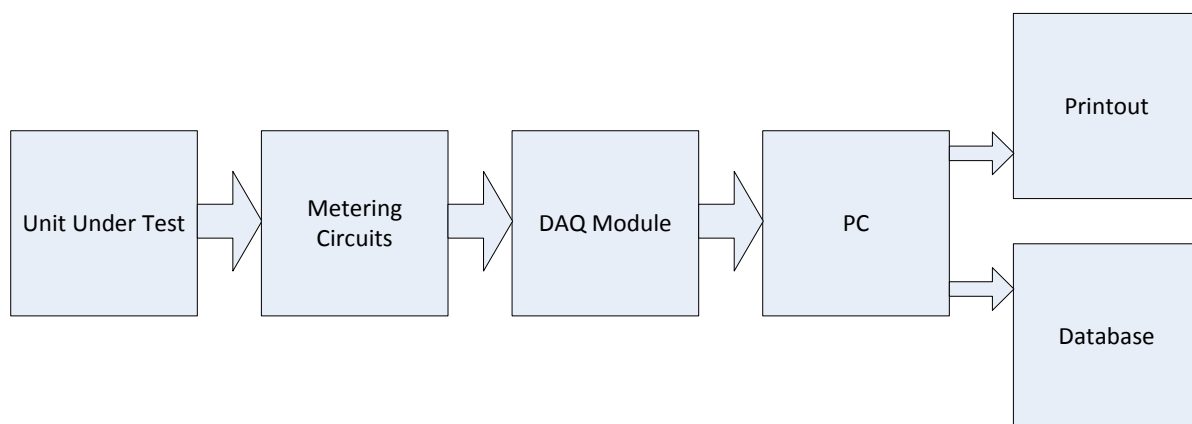## 2.6. Implemented Design Solution

Figure 2.6.1. Automated Actuator Inspection Device Block Diagram

ECE 480 Design Team 6 implemented the Automated Actuator Inspection design shown in Figure 2.6.1. The unit under test interfaces directly with preconditioning circuits designed by the team. These circuits transform and scale the raw signals received from the unit under test into usable inputs, as defined by the data acquisition module specifications.

The data acquisition module interfaces with a PC using USB, as the preconditioned inputs are communicated to a National Instruments LabVIEW environment. The LabVIEW environment performs waveform analysis and other calculations to derive the desired voltage, current, resistance and capacitance measurements, as well as plots the desired statistics outlined in the design specification. The derived information from LabVIEW is printed out in a format similar to the manual inspection method, as well as input into Microsoft Access where an inspection history database is compiled.

The device will be powered through a power supply designed by the team. It converts a standard wall outlet 120V AC into 5V DC, 12V DC and 24V DC to power the actuator for inspection, as well as to power the team's preconditioning circuits.

The Automated Actuator Inspection Device's housing consists of a bottom enclosure, a rotating base and safety shield. The bottom enclosure contains and isolates the device's power supply, preconditioning circuits, data acquisition module, and induction motor. The rotating base is powered by the induction motor for automated Hall Effect device inspection. The safety shield covers the rotating base, which spins only when the lid is closed to protect the user from moving parts.

2.7. Budget

Part Name	Cost/ea.	Qty.	Total Cost
Data Acquisition Module	$150.00	1	$150.00
Induction Motor	$200.00	1	$200.00
Device Housing Supplies	$100.00	1	$100.00
PCB Fabrication (ECE Shop)	$0.00	1	$0.00
Common Circuit Components (ECE Shop)	$0.00	1	$0.00
Specialized Circuit Components	$50.00	1	$50.00
TOTAL PROJECT COST			**$500.00**

Table 2.7.1. Automated Actuator Inspection Device Initial Budget Estimates

ECE 480 Design Team 6 was presented with an initial budget of $500.00 for the Automated Actuator Inspection Device. Table 2.7.1 shows the team's initial budget estimates. Many of the components needed to develop the metering circuits and power supply, in addition to PCB fabrication, were assumed to be available free of charge, courtesy of the MSU ECE Shop.

2.8. Gantt Chart

		Task Name	Duration	Start	Finish	Resource Names
	1	⊟ **Initial Organization Phase**	**12 days**	**Fri 1/30/09**	**Mon 2/16/09**	**All**
	2	Form team and trade contact information	1 day	Fri 1/30/09	Fri 1/30/09	All
	3	Meet with Dr. Ayres	1 day	Mon 2/2/09	Mon 2/2/09	Stephen
	4	Meet with BorgWarner to clarify project details	5 days	Tue 2/3/09	Mon 2/9/09	All
	5	Pick up test units	5 days	Tue 2/10/09	Mon 2/16/09	Josh
	6					
	7	⊟ **Project Research**	**22 days**	**Tue 2/10/09**	**Wed 3/11/09**	
	8	Define project specifications	5 days	Tue 2/10/09	Mon 2/16/09	All
	9	Brainstorm and research for similar diagnostic devices	12 days	Tue 2/17/09	Wed 3/4/09	All
	10	Decide on best solution and assign technical tasks	5 days	Thu 3/5/09	Wed 3/11/09	All
	11					
	12	⊟ **Design Phase**	**18 days**	**Thu 3/12/09**	**Mon 4/6/09**	
	13	⊟ **Design power supply**	**18 days**	**Thu 3/12/09**	**Mon 4/6/09**	**Josh**
	14	Research transformers, chips, circuits, etc	5 days	Thu 3/12/09	Wed 3/18/09	Josh
	15	Order parts	5 days	Thu 3/19/09	Wed 3/25/09	Josh
	16	Build power supply	2 days	Thu 3/26/09	Fri 3/27/09	Josh
	17	Test power supply	3 days	Mon 3/30/09	Wed 4/1/09	Josh
	18	Make needed corrections	3 days	Thu 4/2/09	Mon 4/6/09	Josh
	19					
	20	⊟ **Design method to conduct circuit readings**	**18 days**	**Thu 3/12/09**	**Mon 4/6/09**	**Codie**
	21	Research commercial meters and circuitry	5 days	Thu 3/12/09	Wed 3/18/09	Codie
	22	Order parts	5 days	Thu 3/19/09	Wed 3/25/09	Codie
	23	Build circuits	2 days	Thu 3/26/09	Fri 3/27/09	Codie
	24	Test circuits	3 days	Mon 3/30/09	Wed 4/1/09	Codie
	25	Make needed corrections	3 days	Thu 4/2/09	Mon 4/6/09	Codie
	26					
	27	⊟ **LabVIEW Interface**	**18 days**	**Thu 3/12/09**	**Mon 4/6/09**	**Jacob**
	28	Research LabVIEW abilities	2 days	Thu 3/12/09	Fri 3/13/09	Jacob
	29	Order data acquisition module	5 days	Mon 3/16/09	Fri 3/20/09	Jacob
	30	Build LabVIEW VI	6 days	Fri 3/20/09	Fri 3/27/09	Jacob
	31	Test circuit/PC interface with LabVIEW VI	3 days	Mon 3/30/09	Wed 4/1/09	Jacob
	32	Make needed corrections	3 days	Thu 4/2/09	Mon 4/6/09	Jacob
	33					
	34	⊟ **Design fan and meter housing**	**18 days**	**Thu 3/12/09**	**Mon 4/6/09**	**Stephen**
	35	Research electric motor to rotate fan	5 days	Thu 3/12/09	Wed 3/18/09	Stephen
	36	Design motor housing	1 day	Thu 3/19/09	Thu 3/19/09	Stephen
	37	Build motor housing	5 days	Fri 3/20/09	Thu 3/26/09	Stephen
	38					
	39	Design meter housing	1 day	Mon 3/30/09	Mon 3/30/09	Stephen
	40	Build meter housing	5 days	Tue 3/31/09	Mon 4/6/09	Stephen
	41					
	42	Design fan clutch actuator housing	1 day	Thu 3/12/09	Thu 3/12/09	Stephen
	43	Build fan clutch actuator housing	5 days	Fri 3/13/09	Thu 3/19/09	Stephen
	44					
	45	⊟ **Prototyping Phase**	**18 days**	**Tue 4/7/09**	**Thu 4/30/09**	
	46	Integrate all pieces	3 days	Tue 4/7/09	Thu 4/9/09	All
	47	Test prototype	6 days	Fri 4/10/09	Fri 4/17/09	All
	48	Compare results with project specifications	3 days	Mon 4/20/09	Wed 4/22/09	All
	49	Refine final design and make needed changes	6 days	Thu 4/23/09	Thu 4/30/09	All

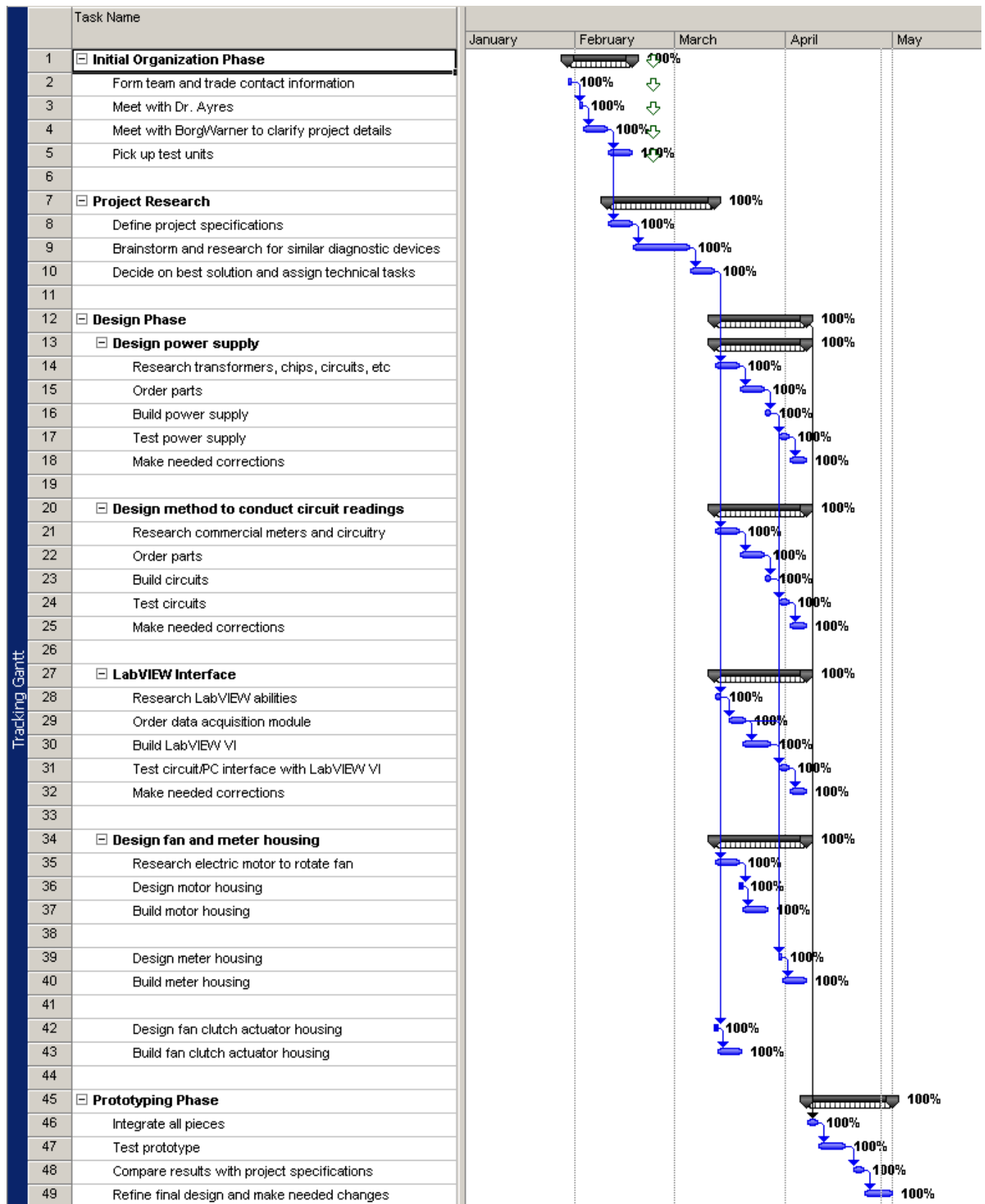Figure 2.8.1. Automated Actuator Inspection Device Gantt Chart Milestones

Figure 2.8.2. Automated Actuator Inspection Device Gantt Chart Timeline

Figures 2.8.1 and 2.8.2 show ECE 480 Design Team 6's Gantt Chart. The Gantt Chart was used for tracking the design progress of the Automated Actuator Inspection Device. It outlines the work breakdown structure of the project, including assigned tasks and set milestones. The Gantt Chart was continuously updated throughout the design process to gauge team progress and reorganize project priorities.

3. Technical Description

The Automated Actuator Inspection Device is comprised of four key components: the metering circuitry, power supply, device housing and fan rotation, and automation and database storage.

3.1. Hardware Design

3.1.1. Metering Circuitry

Below is a list of the components used in the switching/metering circuitry:

- NI USB-6008 Data Acquisition Module
- DB202BDJ Analog Switch IC
- MM74HC4514 4-to-16 Decoder IC
- LM358 Dual OP-AMP IC
- LM555 Timer IC
- ACS712 5A Current Sensor IC
- 2N2222 NPN Transistor
- 1N4148 Diode
- 64W10K Precision Multi-turn Potentiometer
- EC2-5NJ 2A DPDT Relay
- Various resistors/capacitors

One of the requirements for the new design was that it had to interface with a PC and be automated through software control. The decision was made to use National Instruments' USB-6008 Data Acquisition Module (DAQ) as the "in-between" for the metering circuitry and the PC. Since the module is produced by NI, there is extensive support in the LabVIEW

environment. The module itself is a small device that has a USB port in the back, a terminal of analog I/O on one side, and a terminal of digital I/O on the other side. All I/O operations from the PC to the circuit and back, including running the tests and gathering results, is controlled in LabVIEW through the module.

The basic function of the circuitry is to read in a binary code (4-bit) from the data acquisition module, and from there, conducts tests on the actuator. Every test is given a specific code; for example, the four continuity tests are given binary codes 3, 4, 5 and 6. Once the code is given to the circuit, the module can then read in a voltage or frequency from its analog inputs. Software is used to convert this measurement into an actual component value.

When the module sends a binary code to the circuit, the code is sent to the input control lines of a 4-to-16 decoder. The number of decoder outputs equals 2^(# of control inputs), and since 4-bit codes are used, a 4-to-16 decoder was necessary. When the decoder receives a code, it forces one of its output lines to go to logic high voltage (>2.5V), while all others are low. This signal is connected to all the components needed to be controlled for that specific test.

For the 5V DC speed signal test, non-inverting op-amp circuitry is used. The OP-AMP is an LM358 because of its higher supply voltage rating (running from the team's 24V DC supply), and because it features 2 OP-AMPs in a single 8-pin DIP, saving space. This test is given decoder code S1. When S1 is on, the necessary analog switches are closed to conduct the speed signal test (see Appendix 6.3.1). 5V is applied at the non-inverting terminal. Because an OP-AMP cannot have a voltage drop across its inverting and non-inverting terminals, the voltage at the non-inverting terminal has to somehow become the voltage at the other terminal. With the non-inverting OP-AMP topology, the OP-AMP output voltage will be somewhere above 5V. The voltage drop across the 1kΩ potentiometer will be enough so that, regardless of what the output voltage is, the voltage at its inverting terminal will be forced to 5V. The inverting terminal in the schematic is directly connected to pin C of the actuator, creating 5V there. The current going into the actuator can be measured by:

$$I_{ss} = \frac{V_{out} - 5V}{R_{potentiometer}}$$

The output voltage is measured after the switch so that the switch's non-linear resistance (around 45Ω) is not a factor. The speed signal line of the actuator (pin D) is connected through a switch to the data acquisition module analog input. The decoder signal is also connected to the base of an NPN transistor, which grounds the sensor (pin E).

For the 12V DC speed signal test, it follows the same procedure as the 5V DC speed signal test, except that 12V is applied to the non-inverting terminal of the OP-AMP, and the inverting terminal is connected to pin B of the actuator instead of pin C as above (see Appendix 6.3.2).

To measure the coil suppression diode amperage, instead of using analog switches like the ones used in the speed signal test, it was decided to use a 2A DPDT (double-pole, double-throw) relay. Double-pole, double-throw means that a single mechanism controls both switches inside the two-switch relay. Relays have almost no resistance when connected, and can handle a much larger current, and more current is expected than what an analog switch can handle (greater than 30mA). Decoder signal S9 is used to control this test. When it goes high, the necessary switches are closed to activate the test (see Appendix 6.3.3). The decoder is connected to an NPN transistor, which will then connect 5V and the relay coil. The other end of the relay coil is always grounded. When S9 goes high, current flows through the coil, and the relay switches close. When this happens, 5V is connected to a 10Ω 10W power resistor that is connected to pin F of the actuator. Pin A becomes grounded, and voltage is measured to the right of the resistor (see Appendix 6.3.3) with the data acquisition module. The amperage is then found by:

$$I_{diode} = \frac{5V - V_{test}}{10\Omega}$$

For coil amperage and coil resistance, both tests can be run simultaneously, using decoder line S12. If 12V DC is applied to pin A of the actuator, and the current at pin A is measured (coil amperage test), then the resistance is calculated as:

$$R_{coil} = \frac{12V}{I_{pinA}}$$

Once again for this test, a 2A relay was used, because up to 1.3A is expected. When the relay switches close, 12V is connected to pin A of the actuator, and pin F is grounded. However, between 12V and pin A is the ACS712 current sensor IC (see Appendix 6.3.4). It is a Hall Effect device that senses current flowing through its terminals, and its output voltage is a linear function of that current:

$$I_{coil} = \frac{V_{out} - V_{offset}}{slope}$$

V_{offset} is V_{out} when I=0, which is usually half of the supply voltage to the chip. The path the current takes through the IC has resistance of about 1mΩ, so its effect on the conduction path is undetectable. When the test is on, current flows through the circuit, and the data acquisition module measures the output voltage of the current sensor. The software converts the voltage value to its corresponding current value.

For continuity tests between the coil (pin A of the actuator) and any other pin to pass, the measured resistance must be larger than 10MΩ. For this test, a voltage divider is set up, using an 8.2MΩ resistor as the fixed resistor on the board (see Appendix 6.3.5). 8.2MΩ was chosen as the fixed resistor value because it is close to 10MΩ, so a voltage divider would work well. Each continuity test is the same, so the description of the test controlled by decoder line S3 is the same description for the other continuity tests as well (S4, S5 and S6). When S3 goes high, it connects pin A of the actuator to a voltage source through a 2N2222 transistor. Because the

voltage at the base of the transistor is about 5V, the maximum voltage across the transistor from the voltage source to pin A will be around 4.6V. Also, S3 closes an analog switch between pin B and the 8.2MΩ resistor. If there was a connection of 10MΩ between pin A and pin B, then a voltage divider would be created with 10MΩ in series with 8.2MΩ. With these values, there would be around 2.1V at the non-grounded end of the 8.2MΩ resistor, due to the equation:

$$V_{continuity} = 4.6V \frac{8.2M\Omega}{8.2M\Omega + R_{continuity}}$$

where $R_{continuity}$ is the resistance between pin A and pin B, which is being calculated as 10MΩ. As the resistance between pin A and pin B increases, the voltage between the two decreases, and vice versa. Therefore, the voltage at the non-grounded end of the 8.2MΩ resistor can be read by the data acquisition module, and if the voltage is less than or equal to 2.1V, the test passes. If it is greater, the test fails.

The pin B to C resistance test is controlled by decoder line S7. This test is exactly like the coil suppression diode amperage test, except that the software calculations are slightly different. When the switches close, 5V DC is connected to pin B of the actuator through a 560Ω resistor, and pin C is grounded. 560Ω was the value chosen for the fixed resistor because it is close to the expected resistance value from pin B to pin C, so this voltage divider works well. The voltage is read by the data acquisition module to the right of the resistor (see Appendix 6.3.6). The current through that resistor can be calculated by:

$$I_{resistor} = \frac{5V - V_{out}}{560\Omega}$$

There is another resistance to factor in, which is the resistance between pin B and pin C. Therefore, there will be some voltage (V_{out}) at pin B after going through the 560Ω resistor.

Because the current at pin B is known by the equation above, the resistance from pin B to pin C can then be calculated as:

$$R_{pinB} = \frac{V_{pinB}}{I_{resistor}}$$

The 22nF capacitor test is controlled by decoder line S14. An LM555 timer is used in astable mode (see LM555 datasheet). When S14 goes high, an analog switch closes, connecting timer pin 6 to pin D of the actuator, which is the positive terminal of the 22nF capacitor (see Appendix 6.3.7). S14 also connects pin E to ground through a 2N2222 transistor. Once this happens, the timer sends a frequency through timer pin 3 to the data acquisition module. The frequency is proportional to the capacitance, and the capacitance can be calculated by the equation:

$$C = \frac{1.44}{[100k\Omega + 2(100k\Omega)]f}$$

The expected frequency is below 500Hz, since the data acquisition module cannot sample fast enough for high frequency readings.

Adding test circuitry to the design was an easy task, once the control framework was in place. For example, after completing the design for the speed signal tests, the next test added was the coil suppression diode amperage test. First, a decoder control line was allocated to the new test, and accordingly, a 4-bit code. The actual testing circuitry was already designed (see Appendix 6.3.8). For new testing circuitry, it has to be decided where and how to connect the pins of the actuator. For this new test, a relay was used and controlled by the allocated decoder line. The test point that connects to the analog input of the module is connected through an analog switch that is also controlled by the decoder line. In this way, test circuitry

can be added easily. If more control lines are needed than what is available on a 4-to-16 decoder, decoder arrays can be created using 5-bit codes, all the way up to 8-bit codes.

The main challenge with this design was getting a high level of accuracy and incorporating the circuitry to control and switch the different tests, all while using common, inexpensive components. For example, the speed signal test measures current in the 10mA range. The solution to this problem came in different forms, since there were a variety of tests performed. For the example above, OP-AMP circuitry was used that can very accurately measure small currents in the 10mA range, and is also very inexpensive (cost of a common OP-AMP and a few resistors/capacitors).

The trade-off for using this circuitry is that it is more complex than using a more expensive current sensor, and the OP-AMP configuration used in this way requires a voltage supply/voltage output capability that is much higher (possibly double) than the voltage required for the speed signal tests. It was easier to measure larger currents, because current sensors are commonly made to measure greater than 1A. A very inexpensive hall effect IC was used.

Another challenge came while trying to incorporate the switching mechanisms. Sometimes, relays were the best choice due to negligible contact resistance and high current capability. However, they are larger, require more power to turn on, and also cannot be directly driven by TTL (use an extra transistor to turn on the relay from a logic signal). Analog switch ICs were used many times because they are small and can be controlled directly from TTL. The problem with analog switch ICs is that they cannot handle high voltage/currents, and they also have a non-linear resistance associated with their contacts when the switch is closed. The combination of these two switching mechanisms allowed us to run the tests.

An unexpected issue towards the end of the project was with the data acquisition module. After further research, it was discovered that while many commercial multimeters have internal

impedance greater than 10MΩ, the module's is only 144kΩ. As the circuit's impedance approaches that of the multimeter (or data acquisition module), the measurements become increasingly skewed to the point that they are not useful. As an example, measuring voltage in a voltage divider with a high-end multimeter when the resistors are large (greater than 1MΩ) creates significant error. Other times, the module analog inputs float when they seemingly should not. The solutions are to get a more costly module with higher input impedance, or use voltage follower OP-AMP circuitry. The decision was to go with OP-AMP circuitry. However, a better solution is to use a better module.

The final challenge was how to measure the value of the 100nF capacitor in the actuator. At this point, there is not a way to do it with the current design of the metering circuitry.

3.1.2. Power Generation

The Automated Actuator Inspection Device's power supply needed to meet two main considerations: robustness and low cost. It needed to function properly during inspection with little monetary investment, as the team's budget was small and spread thin throughout the project. The planned design requirements for the power supply included steady 5V DC and 12V DC outputs, and current output around 0.5A, all from a 120V AC wall outlet input. These outputs are required to power the metering circuitry, as well as the fan clutch actuator.

The initial power supply design that was adopted was very robust. It took in 120V AC, and stepped it down through an F-90X transformer, which gave the supply a solid 32V AC to be manipulated to obtain the desired outputs. This output was then passed through a rectifier to attain a DC voltage. Next, the output of the rectifier was input to two LM78 voltage regulators at fixed output voltages of 5V DC and 12V DC. The inputs of these regulators needed to be as close to DC signals as possible, so 0.1μF capacitors were added. These capacitors helped to eliminate oscillations within the signal.

Once the power supply was built, a problem came about in testing. The current predicted in the initial design was too small for the working design of the metering circuitry. Instead of 0.5A, the circuitry required around 1.5A, as well as another voltage supply of 24V DC. This 24V DC was required to power the test switching circuitry, and was also overlooked in the actuator test requirements. Given this problem, a different regulator was chosen to meet the new requirements. The LM317 regulator provides an adjustable output that is varied by a change in resistance at the output. The LM317 can be set to a range of 8V DC to 30V DC, and has a current rating of 1.5A. The LM317 is used to generate all three of the DC outputs.

Once the LM317 was added, more problems arose. The voltage output from the rectifier was not steady enough, even with a 0.1μF capacitor at the input. The oscillations in the output prevented the relays in the circuitry from switching. Also, too much heat was being dissipated from the 0.1μF capacitors. Both of these problems were solved by putting a larger capacitor at the input, diminishing the oscillations and cutting back on heat dissipation. Once the larger capacitor was connected, the oscillations at the output were minimal and little heat was dissipated.

As the power supply underwent more testing, another problem came to the forefront. The voltage output at the regulators began to steadily fall when the supply had been on a long time. This was due to internal heat protection inside the regulators, preventing them from melting. The regulator dissipated too much heat, and in turn, activated the protection circuitry. As such, heatsinks were added to displace the heat and stop the protection circuitry from activating. A fan was also attached to the power supply, to further decrease the heat dissipation.

After further testing, the power supply encountered no more problems. The final power supply design can be seen in Appendix 6.3.10.

3.1.3. Device Housing and Fan Rotation

The physical layout for the AAID may be broken up into four sections: the bottom, shield, baseplate and stepper motor.
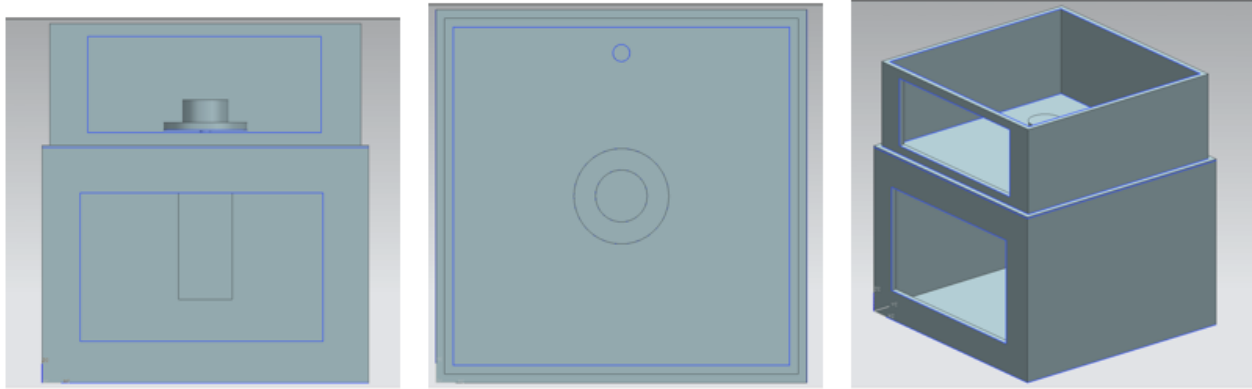

Figure 3.1.3.1. Automated Actuator Inspection Device Housing Models

Figure 3.1.3.1 shows CAD models of the Automated Actuator Inspection Device housing (see Appendix 6.3.11). The bottom section measures 21.5" x 21.5" x 15.5" and is constructed from 1/2" plywood. It houses the stepper motor, power supply and metering circuitry. The large size equates to a stable base during operation. As heavy fan clutch actuators are tested, this box is able to safely support the weight and momentum resulting from the fans rotation.

The baseplate rests on top of the bottom structure. Constructed from 21.5" x 21.5" x 1/8" aluminum, its purpose is to support the weight of the fans during testing and hold the motor in place. This is necessary because the stepper motor is built to rotate a shaft, not act as a support for heavy loads. If a large enough fan was placed on the motor directly, it could tip or break due to the weight.

The rotation apparatus rests on the baseplate. A more detailed look of this piece is shown In Figure 3.1.3.2:
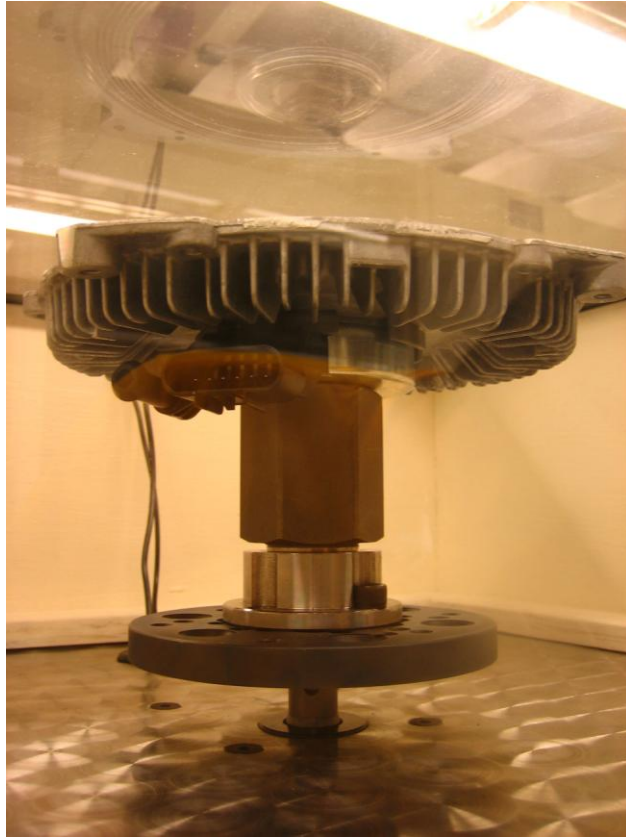
Figure 3.1.3.2. Device Rotation Apparatus

The stepper motor's shaft connects to the circular plate in the middle. A threaded shaft is secured to this plate to securely fasten fans during rotation. The circular plate rotates smoothly, directly from the stepper motor shaft.

The top portion of the device housing is the shield, resting on the aluminum baseplate. A screw in each corner holds the shield, baseplate and bottom sections together. Constructed from the same ½" plywood as the bottom section, the shield measures 20.5" x 20.5" x 8". The shield's purpose is to provide protection. The fan clutch will be rotating while undergoing inspection, raising the possibility of fingers, clothing or other objects being caught in the motion. The result could be damage or injury. The shield features two Plexiglas pieces: one as the lid, and the other as a window. This combination allows the user to view the fan clutch while it is under test.

In addition to ensuring safety while the fan clutch rotates, the shield also provides protection as fan clutches are mounted and dismounted. The circuit in Figure 3.1.3.3 accomplishes this feat:
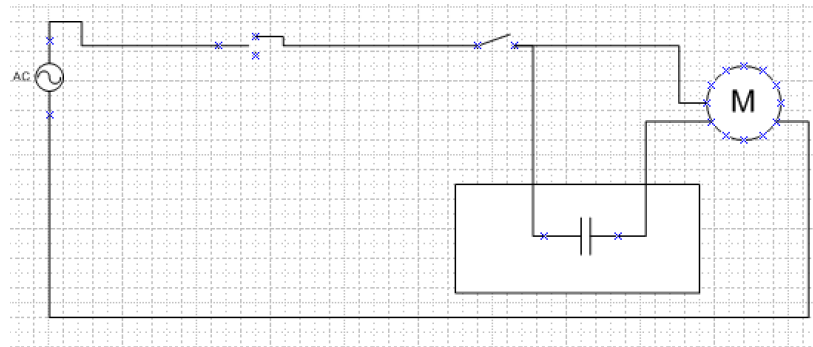

Figure 3.1.3.3. Device Housing Safety Switch Circuit

One toggle switch acts as an on/off control, while the other completes the circuit. This second switch depresses with a hinge lever. This hinge switch is located on the shield; when the lid is closed, it depresses the switch's contact and completes the circuit path. This means that even if the stepper motor is turned on, the motor will not rotate while the lid is open. Both switches act as single-pull, single-throw components. The hinge lever switch is a SS-5LGT Snap Action Switch, manufactured by Omron. Its layout can be seen in Figure 3.1.3.4:
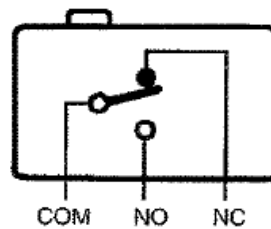

Figure 3.1.3.4. SS-5LGT Snap Action Switch Circuit Layout

Although designed for double-pull, double-throw operation, both switches are utilized as single-pull, single-throw devices. The normally open terminal connects to the on/off switch, while the common terminal connects to the wall outlet. It is rated for 5A at 125V AC. The internal resistance measures in the milliohm range, and the 30 million operations lifecycle

makes this robust component an ideal choice. The on/off switch acts very much the same way: it is rated for 2.5A, well within the required limits.

When both switches are in the "on" position, power is supplied to stepper motor. The VHI590A-120U stepper motor is manufactured by Orientalmotor. This 90W motor draws 1.56A at peak operation. A gear ratio of 120:1 steps down the angular speed. The 350 lb-in-rated torque gives this motor versatility to be used in a number of applications.

Other notable specifications begin with the motor's power supply. Its ability to be plugged directly into the wall outlet makes for seamless integration with the team's current power supply and choice of switches. It possesses enough torque to rotate every fan clutch in BorgWarner's inventory, with the capability to handle larger loads for potential future designs. The motor operates at 15 rpm – a perfect speed for inspection.

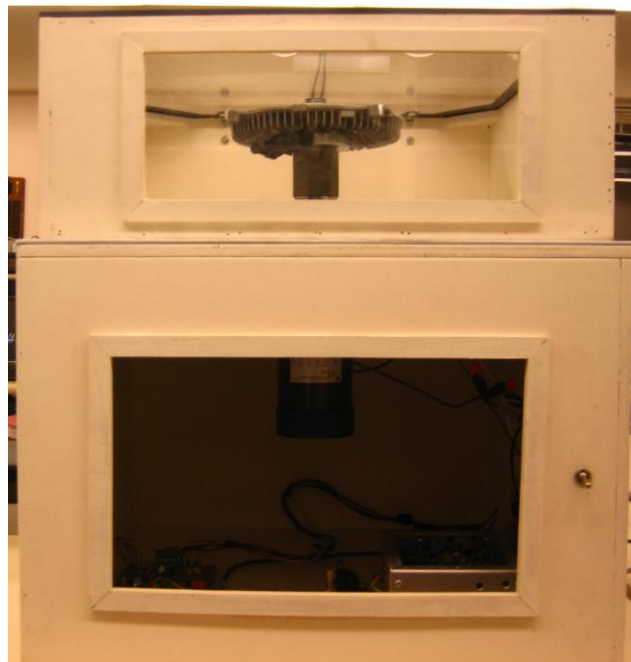## 3.2. Hardware Implementation

Figure 3.2.1. Physical Device Hardware Layout

The physical layout of the Automated Actuator Inspection Device is shown in Figure 3.2.1. It provides a compressed, protected shelter for the power supply, metering circuitry, data acquisition module, and stepper motor. Each device is carefully laid out so as to not damage another.

Because the power supply has an external fan, it is oriented such that air is circulated throughout the bottom housing. It is close enough to the left wall such that an on/off switch can be attached to the outside for easy access.

Located ten inches away from the power supply is the metering circuitry. Much care is taken to secure the circuit board to the bottom section while protecting its fragile connections. Spacers are attached to the bottom of the circuit and attached to the housing with screws.
The metering circuitry connects to the actuator during inspection through a one inch hole drilled in the back side of the aluminum base plate. A single 1-1/8" hole on the left side of the bottom section provides a path to the outside for the stepper motor and power supply cords. The data acquisition module's USB cable is also fed through this hole for connection to the PC.

The final aspect of the physical design for the product is with the stepper motor's safety mechanisms. The power switch for the motor is located on the front side of the bottom enclosure, while the power supply switch is on the left. The hinge switch is located at the top of the shield, where the lid meets the walls of the shield.

3.3. Software and Interface Design

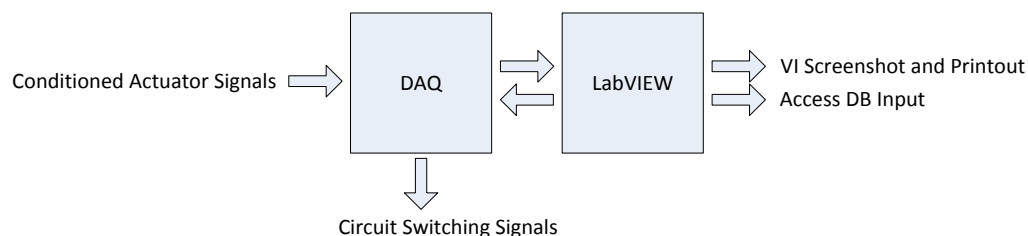### 3.3.1. Automation and Database Storage

Figure 3.3.1.1. Automation and Database Storage Block Diagram

Figure 3.3.1.1 shows the implemented design for the Automated Actuator Inspection Device's automation and database storage interface. The conditioned actuator signals from the metering circuitry serve as analog inputs to the data acquisition module, and are processed in the LabVIEW VI. The VI performs waveform measurements for values required by the metering circuitry equations for voltage, current, resistance and capacitance readings. The equations are carried out, and inspection result values are returned. The results are then compared to the proper operation ranges for the actuator under test. The VI then outputs a digital decoder signal to the data acquisition module, which enables the switching circuitry and proceeds with the next test. After the inspection process is complete, the LabVIEW VI prints out a screenshot of itself for a hardcopy test report, and also stores the results as a Microsoft Access database recordset for comparison with past and future test runs.

The software and interface design implementation requires the following components:

- National Instruments LabVIEW 8.5 Professional Development System
- National Instruments LabVIEW Database Connectivity Toolkit
- National Instruments USB-6008 Multifunction Data Acquisition Module
- National Instruments DAQmx Software
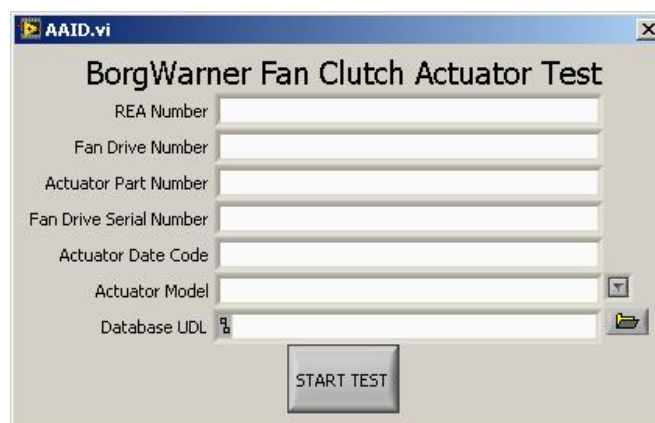- Microsoft Office Access 2003

Figure 3.3.1.2. Automated Actuator Inspection Device Start GUI

Figures 3.3.1.2 shows the start graphical user interface (GUI) for the Automated Actuator Inspection Device interface. The start GUI prompts the user for the actuator under test's serial numbers, as well an actuator model selection from a drop-down menu, and a path to the test database's universal data link (UDL) file. The UDL file specifies the type of connection to be established between the database and accessing application, as well as the location of the database itself. The Automated Actuator Inspection Device interface uses the Microsoft Jet 4.0 OLE DB Provider connection.
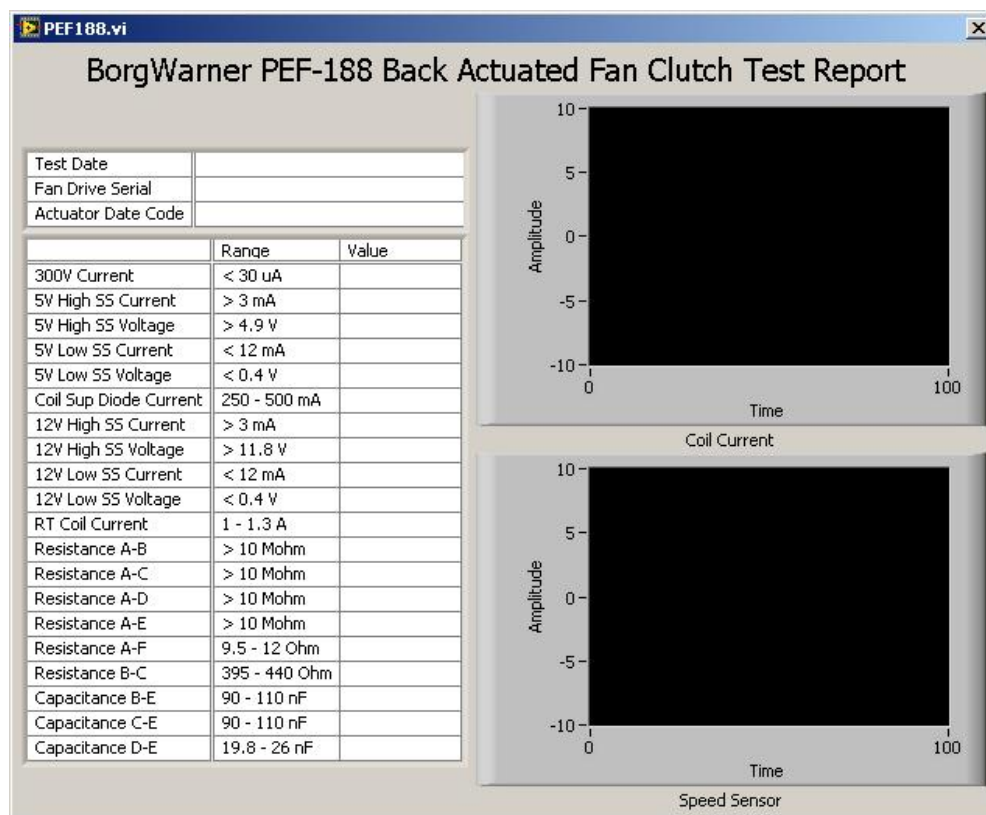

Figure 3.3.1.3. Automated Actuator Inspection Device PEF-188 Test Report GUI

Figures 3.3.1.3 shows the test report GUI for BorgWarner PEF-188 back actuated fan clutches. Descriptive test information, including the test date, fan drive serial number and actuator date code, are taken from the start GUI. The inspection procedure is run, and results are inserted into the test report as they are calculated. The rows become colored green or red as the tests pass or fail, respectively. The coil current chart plots the step signature when 12V DC is applied

to the actuator. The speed sensor chart plots the high and low speed signal voltages as the fan clutch rotates and passes through the Hall Effect device.
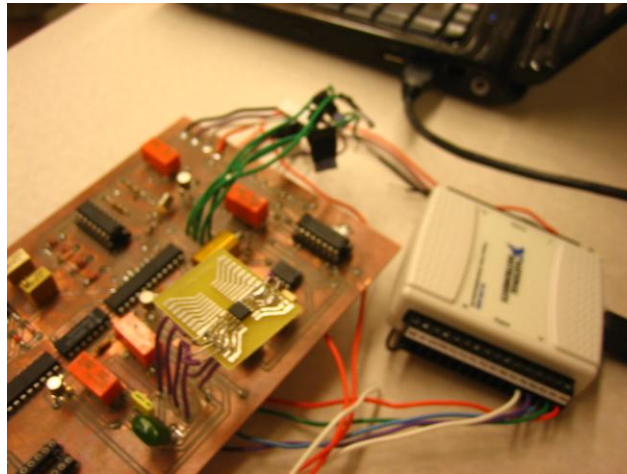
3.4. Software Implementation

Figure 3.4.1. Metering Circuitry – DAQ – PC Interfacing

Figure 3.4.1 shows the connections between the metering circuitry board, the data acquisition module, and the PC. The analog outputs from the circuitry are tied into the analog inputs of the data acquisition module for test processing, and the digital outputs from the module are tied into the inputs of the decoder for test switching.
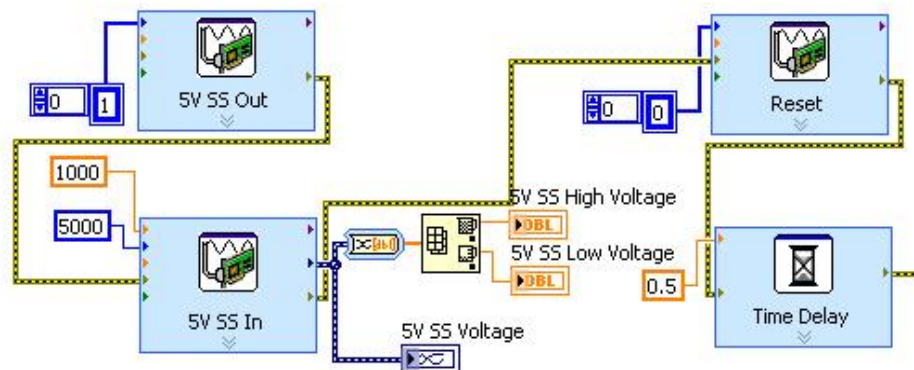

Figure 3.4.2. Test Procedure Block Diagram (5V DC Speed Signal)

Figure 3.4.2 shows the LabVIEW block diagram for test procedures; specifically, the 5V DC speed signal test. A digital decoder signal is written out to the data acquisition module to trigger the specific test. The analog input of the data acquisition module is then sampled for data. The samples are then processed based on the equation corresponding to the test. After processing, a reset signal is written out to the decoder. It is followed by a time delay for propagation, after which, another test can be run. This is the standard procedure for every test, with the only variations being the test decoder signal and its corresponding equation.
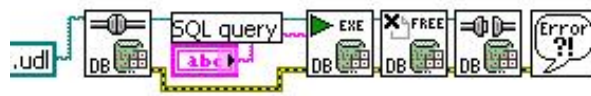

Figure 3.4.3. Database Recordset Entry Procedure Block Diagram

Figure 3.4.3 shows the LabVIEW block diagram for recordset entry into the actuator test database in Microsoft Access. A connection to the test database is created using the UDL file. An INSERT SQL query is executed, creating a recordset in the database with the completed test result values. The recordset reference is then freed, and the database connection is closed. This procedure is executed every time the inspection process completes.

Appendix 6.3.12 shows a VI hierarchy of the LabVIEW software implementation.

4. Functional Design Testing

4.1. Manual Method Comparison

After developing circuits capable of running tests on the actuator, it was necessary to check if the results had acceptable accuracy. To do this, the tests were run on the actuator with a high-end multimeter, whose results became the reference. The meter does not perform capacitance measurements; therefore, a separate capacitance meter was used.

4.2. Results

For the speed signal tests, all the results for the current measurements were very close (within 1mA). The multimeter values were always slightly smaller than the team's design, which is to be expected because of the way the multimeter calculates current, as well as the errors introduced, such as the multimeter's burden voltage. It is possible that the results of the team's design are actually closer to the real current value. The high signal state voltages for both tests were almost exactly the same. The largest difference was with the +5V test, where the difference was 0.03V. The low signal states were both approximately 15mV different from the multimeter's results, which may seem significant when the multimeter gives 65mV and the team's design gives 80mV. However, since the range of acceptable values for the low signal state is 0V to 0.4V, the difference in results leads to an error of only about 4%.

For the coil suppression diode amperage, the multimeter gave a result of 375mA. However, using the same multimeter to measure the voltage at both terminals of the 10Ω resistor used in the test, then using it to measure the resistance of the resistor, the result is 401mA. From this, it can be seen that the multimeter introduces significant error. As expected, the error-created result was smaller than the actual value. This error is not enough to cause the test to fail; however, it is significant. The team's design applies Ohm's Law in this test to produce a very accurate result – 401mA. The power supplies used for testing display the voltage and current output, both of which agree with the results of the team's design.

For the coil current/coil resistance test, a Hall Effect IC is used to measure the current. The IC's voltage output is a linear function of the current passing through it. Once the equation is defined with exact values, it is easy to calculate the current. From calculations made with the IC, measuring currents ranging from 0.25A to 1.35A, the accuracy compared with the power supplies was, at minimum, 95.6% accurate, and normally greater than 97% accurate. Because Ohm's Law is applied to get the coil resistance value, the accuracy is the same.

For the continuity tests, the tests do not necessarily yield a value, but rather a pass/fail status. All of the tests passed using the team's design and available test actuators. A better test is to put a resistor across pin A of the actuator, and one of the other pins to get a result. It should fail if the resistor is less than 10MΩ, which it did through the team's analysis.

For resistance between pins B and C of the actuator, using the multimeter gives a value of 416Ω. The team's design yields 415Ω, which is greater than 99% accurate. Further testing with other resistor values ranging from 100Ω to 1kΩ were conducted: all of the results were accurate.

For the 22nF capacitance test, the capacitance meter used gave a value of 22nF, while the team's design yielded about 20nF. This is close, but only about 91% accurate. A potentiometer was used in the design to "tune" the circuit to make it almost exactly in the range of capacitance the test specifies.

For the 100nF capacitance test, the team does not yet have a circuit design in place, pending implementation of a Wien bridge oscillator.

5. Conclusions

5.1. Summary

ECE 480 Design Team 6 was tasked with creating an automated test device for BorgWarner fan clutch actuators, specifically, the PEF-180 and PEF-188 models, with the latter being the main focus. The tests include specifications from the current test procedures, as well as new inspections, such as time plots of the coil current and speed sensor output.

The team has created a design that meets most of the design criteria. The team designed an enclosure that uses an induction motor provided by BorgWarner that enables the fan clutch to be automatically rotated during inspection. For safety purposes, the enclosure has two

switches: a power switch and a lid switch. The device will not rotate until the lid is closed, even if the power switch is on.

The team created a custom power supply that can output 5V DC, 12V DC, and 24V DC, and is rated for 1.5A at each voltage. It has a 2A fuse located before the regulators to safeguard from burning them out. Although heat was previously an issue, larger heat sinks, ventilation holes, and a large fan were added to the design to lower the temperature during operation. The power supply is used to power the metering circuitry, as well as to supply the actuator with test voltages.

The team's circuit design is able to interface with a PC. It can run seventeen of the nineteen tests from the current PEF-188-model actuator checklist, as well as new time plot inspections, as mentioned previously. The remaining two tests are for the same circuit component (100nF capacitor). At this point, the team's design is unable to retrieve a measurement.

The differences in the checklists for the PEF-180 and PEF-188-model actuators include a 24V DC coil test and extra continuity checks. While the circuit design has not yet been tested on the PEF-180, its schematic is almost identical to the PEF-188 and should operate correctly. Due to time constraints and technical difficulties towards the end of the project, the team was unable to connect the extra tests for the PEF-180 to the PCB. However, proposed solutions with schematics for these tests have been drafted, which will be given to BorgWarner (see Appendix 6.3.9).

The device's software, created in LabVIEW, allows the user to run the tests on the actuator with the click of a mouse. The data is entered into a graphical output, along with the time plots. A passing or failing test is easily recognized in the output, with passing results displayed in green and failed results in red. The data is then made into a hardcopy printout, as well as interfaces with Microsoft Access to create a database for test results.

Once the framework for the design of the Automated Actuator Inspection Device was in place, adding tests was an easy task, under both hardware and software. While the design is not entirely complete, with some revision, it can be a very robust design, expandable to include new measurements.

ECE 480 Design Team 6 was able to show that it is possible to create an accurate, low-cost, automated test device. The team was able to demonstrate a functional, although slightly incomplete, automatic tester. The team designed all the major components, including the housing, power supply, hardware and software for the device. It is a robust framework that is capable of being expanded as needed.

5.2. Final Cost

Part Name	Supplier E=ECE Shop BW=BorgWarner T=Team	Cost/ea.	Qty.	Total Cost
Metering Circuitry				
10-ohm Power Resistor	T	$1.00	1	$1.00
ACS712ELCTR-05B-T Hall Sensor	T	$1.29	1	$1.29
Chip Surface Mount	E	$0.42	6	$2.52
DG202BDJ Analog Switch	T	$1.26	4	$5.04
Dual Operational Amplifier	T	$0.29	1	$0.29
Inverter IC	T	$0.26	1	$0.26
LM2917N-8/NOPB Signal Relay	E	$1.70	4	$6.80
LM555 Timer	T	$0.42	1	$0.42
MM74HC4514N Decoder IC	T	$1.11	2	$2.22
National Instruments USB-6008 DAQ	T	$152.10	1	$152.10
Terminal Blocks	E	$0.79	2	$1.58
Transistor	T	$0.20	6	$1.20
Power Generation				
2 Amp Fuse	E	$2.61	1	$2.61
DC Fan	E	$4.99	1	$4.99
Heatsinks	T	$0.92	3	$2.76
LM371 Voltage Regulators	E	$1.70	3	$5.10
SPST Switch	T	$3.47	1	$3.47
Transformer	E	$23.64	1	$23.64
Device Housing and Fan Rotation				
1/2" x 48" x 96" Inch Plywood	T	$31.96	1	$31.96
21.5" x 21.5" x 1/8" Aluminum	BW	$20.00	1	$20.00
3/16" x 24" x 48" Plexiglas	T	$51.33	1	$51.33
Orientalmotor Stepper Motor	BW	$292.00	1	$292.00
Snap Action Switch	E	$2.15	1	$2.15
Toggle Switch	E	$2.34	1	$2.34
Team Expenditures				$253.34
ECE Shop Expenditures				$51.73
BorgWarner Expenditures				$312.00
TOTAL PROJECT COST				**$617.07**

Table 5.2.1. Automated Actuator Inspection Device Project Expenditures

Table 5.2.1 shows the total components and cost to produce an Automated Actuator Inspection Device. Many of the components were donated, courtesy of BorgWarner and the MSU ECE Shop. Although ECE 480 Design Team 6's share of the total project cost was $253.34, it should be noted that the team spent a total of $540.33 throughout the design process. These extra

expenditures were a result of prototyping, as well as failure of the data acquisition module, leading to repurchase.

5.3. Future Work

Listed here are improvements recommended by ECE 480 Design Team 6 to the design of the Automated Actuator Inspection Device, given relaxed time and budget constraints:

5.3.1. Metering Circuitry Improvements

For the speed signal test, using a small signal current sensor instead of OP-AMPs would make a simpler and cleaner, although more costly solution. For the tests using higher currents, new relays should be used, as the current ones handle a maximum of 2A.

For the 22nF capacitor test, it is assumed that the connection of pin 6 of the timer to the actuator's capacitor has a series resistance of less than 1kΩ. For example, if in a future actuator design, pin D of the actuator was connected to a 2kΩ resistor before connecting to the capacitor, then the frequency output of the timer will not be exactly proportional to the capacitance, which is necessary for an accurate reading. The larger the series resistance, the worse the measurements will be. This issue needs to be addressed.

Overall, using a better DAQ module would increase the device's accuracy and fix many of the problems with the current module. However, even a slightly better module costs significantly more, so a trade-off must be made.

5.3.2. Power Generation Improvements

For future designs, a more reliable power supply needs to be acquired. The power supply designed by ECE 480 Design Team 6 was completed quickly and, although the power supply is robust, it has not gone through rigorous testing. A professionally manufactured power supply would provide a steadier, more reliable power source with a longer lifespan. This reliability would make it easier to implement the power supply into future tester designs.

There is one test that was not implemented in the Automated Actuator Inspection Device, due to time constraints. This test required a 300V DC source to be applied through the fan clutch's solenoid to check its continuity. This test should be implemented in future designs, as it is important in fully verifying the proper operation of fan clutch actuators.

5.3.3. Device Housing and Fan Rotation Improvements

The physical design of the Automated Actuator Inspection Device requires no significant modification. The dimensions can be adjusted so there is less open space. This results in a less expensive housing, since less material is required. The footprint also decreases, making it a more convenient option when being placed in labs.

A larger concern deals with the stepper motor and the safety measures in place. A better solution for protection would be to have electronic safety measures in addition to the mechanical switches. Right now, the PC controls inspection, but not the rotation of the motor. A software-based speed control could provide more safety to the user. In addition, future inspection may require varying rotation speeds, in which a speed control would prove beneficial.

5.3.4. Automation and Database Storage Improvements

Automation and database storage can be improved by continuing development of the Automated Actuator Inspection Device's LabVIEW interface. A basic framework has been laid out in Vis created for automated testing of the PEF-188-model actuator. Although this framework can be duplicated in order to fit future actuator models, a more streamlined approach is desired.

A more streamlined approach can be implemented by further developing the device's interface for higher customization and ease of use. A profile system can be developed and linked to the actuator model drop-down, seen in the device's start GUI. This profile system would be powered by a customization GUI, where the user would be able to create their own test

requirements, citing desired measurements (voltage, current, resistance, capacitance) and acceptable pass ranges.

This expandability was taken into consideration at the beginning of the design process. However, due to unfamiliarity with the actuator circuitry and a prolonged prototyping phase, the customization GUI was not realized. This proposed feature depends on the generic nature of the metering circuitry in being able to read actuator measurements of varying ranges. However, at present, the metering circuitry has been tailored to accommodate PEF-180 and PEF-188-model actuators. Only after the metering circuitry reaches a higher level of versatility can this expandability notion be entertained.

6. Appendix

6.1. Technical Roles and Responsibilities

Each member of ECE 480 Design Team 6 is responsible for technical aspects of the Automated Actuator Inspection Device design. Although they are responsible for overseeing the development of these aspects, the project is a team effort as a whole, and members work in conjunction with one another to facilitate completion. Listed here are the team members' technical roles and responsibilities:

6.1.1. Jacob Co – Automation and Database Storage

Jacob Co was responsible for the automation backbone of the Automated Actuator Inspection Device. His role was vital to the success of the project, as the LabVIEW interface serves as the driving force behind the inspection procedures. The interface is what the device user interacts with throughout inspection – from the input of actuator identifying numbers and selection of the correct model, to the display and storage of results in both printout and database form. In the background, the interface is sending decoder line outputs corresponding to specific actuator tests through the data acquisition module, enabling the correct circuitry on the metering board for inspection.

In addition to facilitating the automation process, Jacob's work was also responsible for processing the input signals from the metering circuitry into usable actuator measurements. This conversion is crucial in being able to compare accurate results to actuator specification ranges. Jacob made the graphical user interface (GUI) as user-friendly and understandable as possible, denoting inspection passes with green highlights and fails with red highlights.

As the automation interface drove the metering circuitry, Jacob worked closely with Codie during development of the Automated Actuator Inspection Device. Given the powerful versatility of the LabVIEW environment and the hurdles of circuit design, Jacob structured the interface to work around the metering circuitry. This was extremely beneficial through the

prototyping phase of the project, where the metering circuitry would undergo major changes and automation needed to be kept intact.

Needing to know the metering circuitry thoroughly in order to successfully implement automation, Jacob also served as a hardware troubleshooter in the finalization stages of the device. As metering components seemed to malfunction, Jacob took a methodical approach in tracing signals from raw actuator input to component output, isolating problems and working with Codie to brainstorm and implement design changes.

6.1.2. Joshua DuBois – Power Generation

Joshua DuBois was responsible for the design and implementation of a reliable power supply. The design had to be low cost due to budget constraints. The power supply was needed to power the actuator under test, as well as the circuitry used for taking measurements. The measurement circuitry required 5V DC, 12V DC, and 24V DC supplies at 1.5A. The fan clutch actuator required, depending on certain models, 5V DC and 12V DC supplies to operate. Each voltage source needed to be designed and implemented.

The implementation of the designs did not always go smoothly, but if any problems arose, Joshua fixed or re-designed the power supply to meet requirements. This led to many design iterations to create a more reliable power supply. Throughout the project, the power supply had to be molded around the measurement circuitry power requirements. These iterations required researching for parts, as well as a re-design of the power supply topography. During each revision, more parts were added, which added to the complexity of Joshua's role. After the power supply design was finalized, Joshua designed its housing and cooling system. It consisted of a metal enclosure with a fan mounted on the side.

Throughout the project, Joshua lent a hand wherever it could be used. When he wasn't working on power generation, Joshua was working with the metering circuitry PCB or the device housing

design. The PCB needed to be built from the ground up, and once the PCB was fabricated by the MSU ECE Shop, the circuit elements had to be soldered to the board. Since Joshua had prior soldering experience, he did most of the initial PCB assembly. Joshua also helped Stephen create the housing design by introducing valuable insights and ideas. Joshua's role was vital in the success of the project.

6.1.3. Stephen Sutara – Device Housing and Fan Rotation

Stephen Sutara was responsible for the housing design, stepper motor and safety measures. He first took measurements of Codie and Joshua's metering circuitry and power supply to have an idea as to how large the housing would need to be. Using modeling software, he designed and drew the schematics for the housing, and worked with the MSU ECE Shop for fabrication.

The stepper motor required examination of many different quantities. Stephen started by determining what requirements the motor would have to meet. To accomplish this, he worked with BorgWarner to learn that the largest fan clutch actuator weighed thirty-five pounds, with a diameter of twelve inches. Next, he had to decide on a motor type, weighing the various advantages and disadvantages of each.

Stephen's last responsibility was the housing shield safety features to ensure no damage or injury occurred. For this he looked, into what switches were available. With the help of his team, Stephen connected the switches to the wall and stepper motor to create the safety system.

In addition to the assigned tasks, Stephen also aided Codie with the metering circuitry and Joshua with the power supply. When the first few circuits were complete, Stephen conducted some of the initial tests and aided in qualifying the results. As the remaining metering circuits were designed, he helped with the construction of the components and the testing of functionality. When the metering circuitry PCB was fabricated, he soldered many of the

components and analyzed the functionality of the design to ensure identical performance to that of the circuit during the prototyping phase.

Stephen aided Josh with the power supply by referencing information from past courses and lectures on possible components and theories. When the power supply was to be built, Stephen helped with the solder and testing. When heat dissipation became a serious issue for the components, he proposed the idea to mount an external fan, which was later implemented.

6.1.4. Codie Wilson – Metering Circuitry

Codie Wilson was responsible for designing the circuitry necessary to conduct fan clutch actuator tests. This includes the design of methods to perform the measurements, and merging them all into a single design, using switching circuitry and digital control. The circuit had to accept 4-bit digital codes from the data acquisition module, and the output had to be either a voltage or frequency, scaled to a range useable by the module.

The first thing Codie had to consider was how to use digital codes from the module as a control for each test. The next thing he had to consider was what type of IC or circuitry would be controlled by that signal, and how it would control what it does. After having a rough outline of the design, Codie had to consider the specifications for all the parts, as components had to be not only compatible with each other, but able to handle the types and magnitude of signals they are expected to operate on. All throughout this process, he was revising the ways to conduct the tests to match the specifications of the components used.

After coming up with a working design, Codie's next task was to create a PCB so that all the components were not sitting on protoboards. The team's design was too large for the typical Eagle PCB layouts that ECE 480 students commonly use for the MSU ECE Shop, so he had to seek out other PCB software and use it to design a larger board. The initial board Codie designed was meant for the PEF-188-model actuator, but he arranged the components such

that after working out any issues with it, the team could easily create a new board and add the remaining tests without increasing the board size or moving any other components. While the metering circuitry design works on the protoboards (and mostly works on the PCB), time-consuming difficulties with the initial board prevented a second board from being designed.

Codie helped Stephen with the wiring of the switches for the housing. He also helped Jacob with the automation. While he did no actual programming/automation in LabVIEW, he was involved in the process of automating the design.

6.2. References

1N4148 Diode Datasheet

http://ronja.twibright.com/datasheets/diode/1N4148_1N4448_5.pdf

2N2222 NPN Transistor Datasheet

http://www.fairchildsemi.com/ds/PN/PN2222A.pdf

ACS712 5A Current Sensor Datasheet

http://www.allegromicro.com/en/Products/Part_Numbers/0712/0712.pdf

DB202B Analog Switch Datasheet

http://www.vishay.com/docs/70037/dg201b.pdf

EC2-5NJ Relay Datasheet

https://www.egr.msu.edu/eceshop/Parts_Inventory/datasheets/5v%20dpdt%20relay.pdf

F-90X Transformer Datasheet

http://triadmagnetics.com/pdf/Page%2058.pdf

LabVIEW Database Connectivity Toolkit User Manual

http://www.ni.com/pdf/manuals/321525c.pdf

LM317 Regular Datasheet

http://www.national.com/ds/LM/LM117.pdf

LM358 OP-AMP Datasheet

http://www.national.com/ds/LM/LM158.pdf

LM555 Timer Datasheet

http://www.national.com/ds/LM/LM555.pdf

MM74HC4514 4-16 Decoder Datasheet

http://www.fairchildsemi.com/ds/MM/MM74HC4514.pdf

NI USB-6008 DAQ Module Datasheet

http://www.tau.ac.il/~electro/pdf_files/computer/ni_6008_ADC_manual.pdf

VHI590A-120U Stepper Motor Datasheet

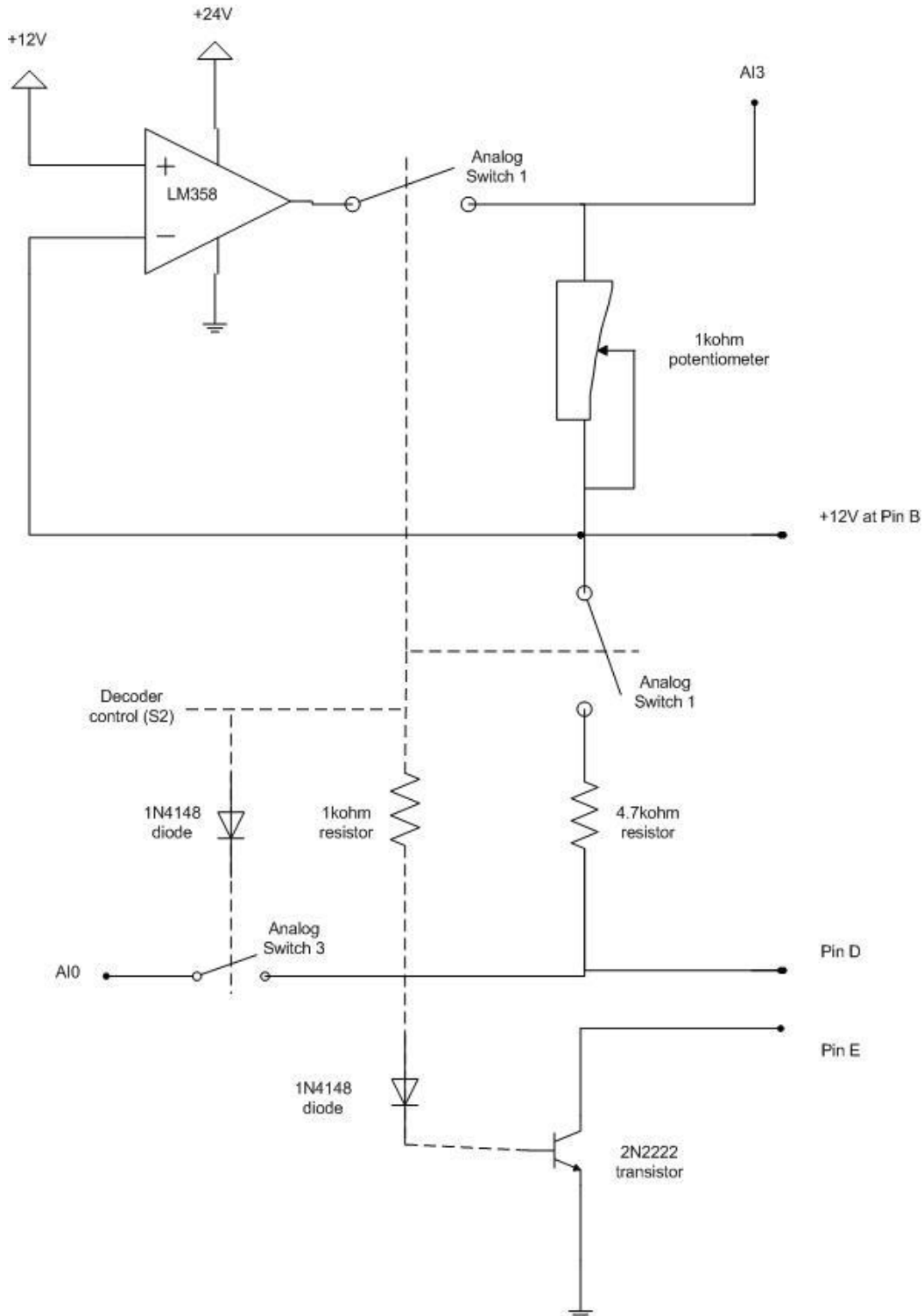http://www.orientalmotor.com/products/pdfs/A_OM/AcInd90.pdf

6.3. Technical Attachments

6.3.1. 5V DC Speed Signal Test Circuit Schematic

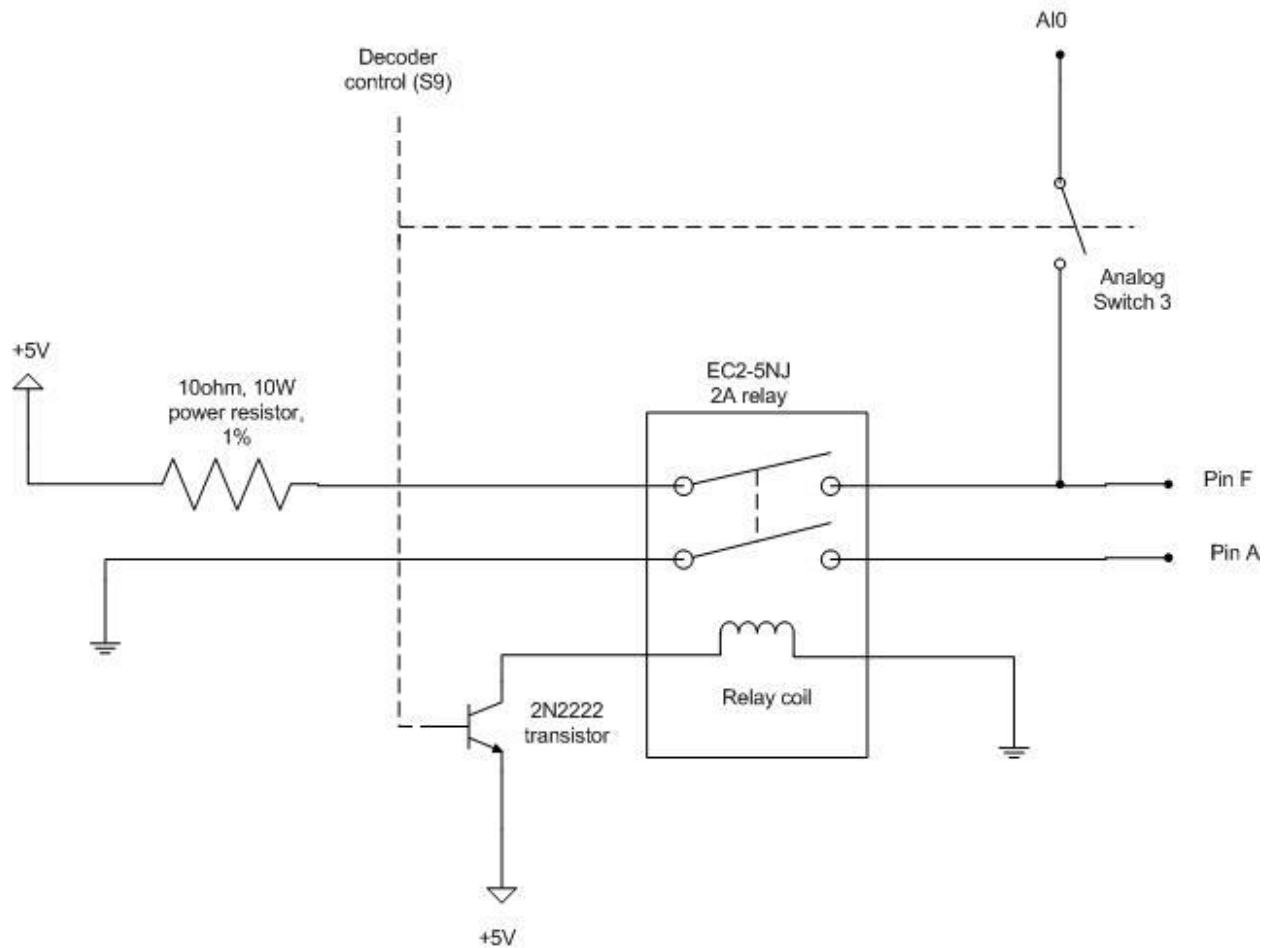+5V Speed Signal Test
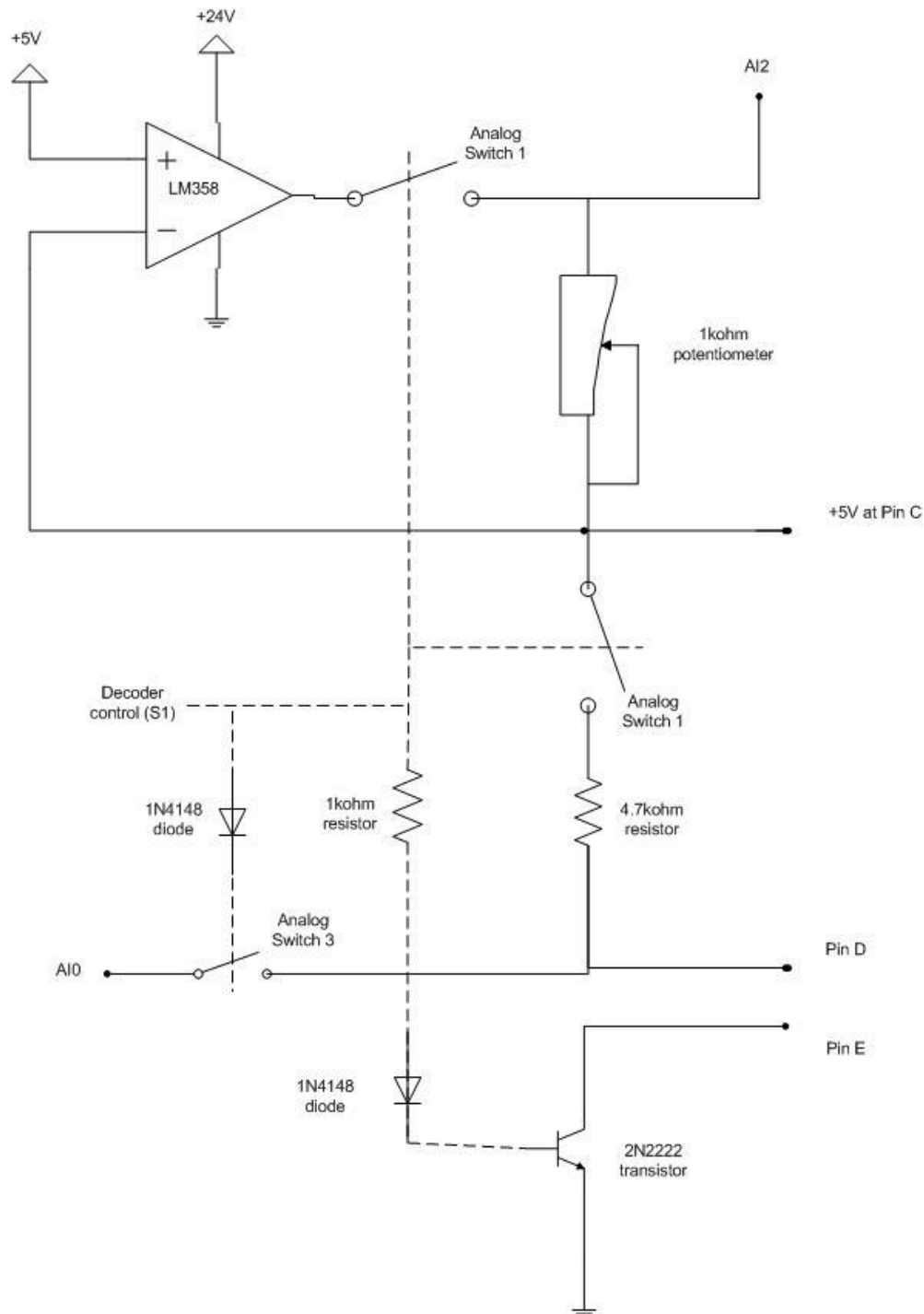
6.3.2. 12V DC Speed Signal Test Circuit Schematic
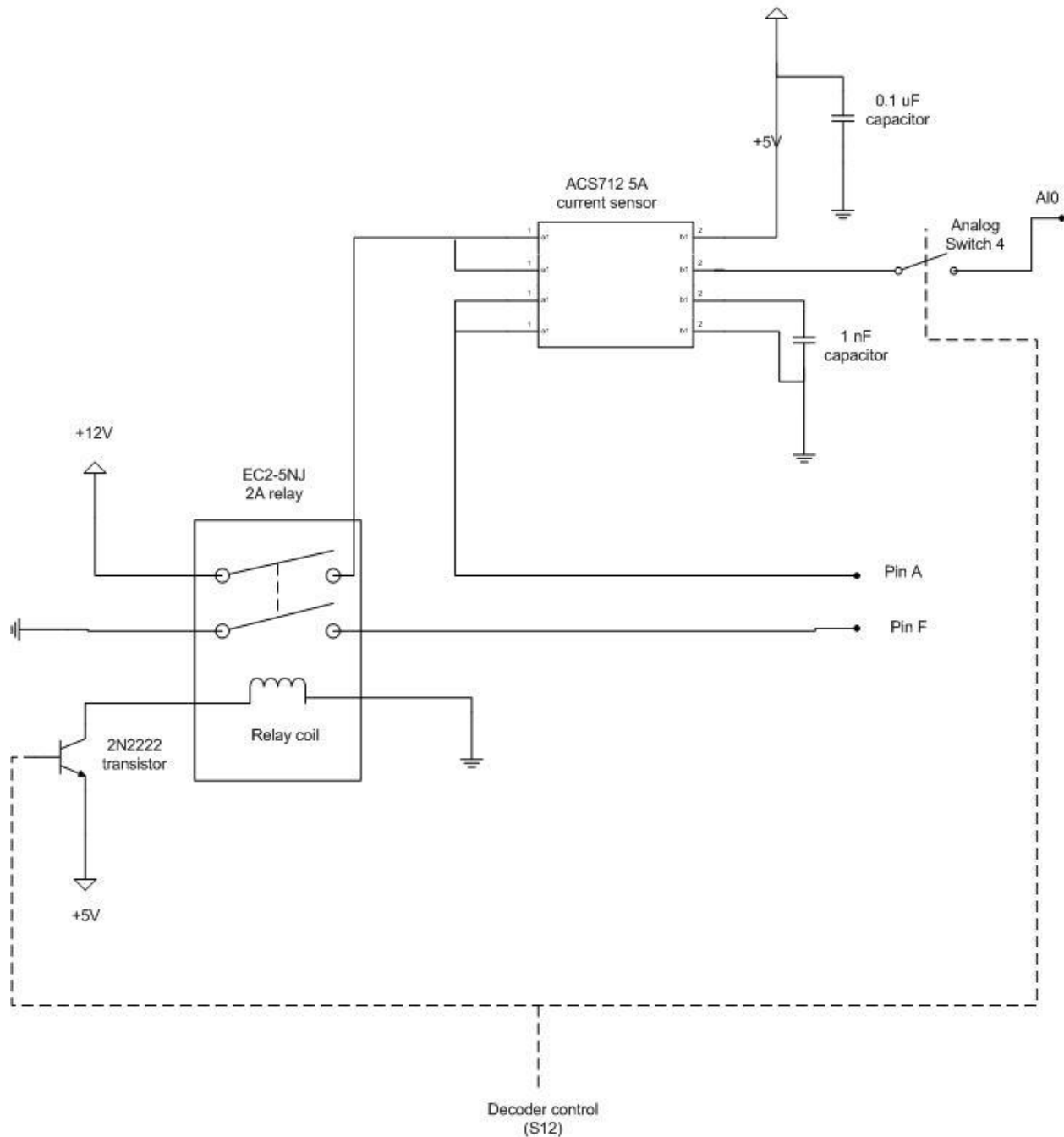

+12V Speed Signal Test

6.3.3. Coil Suppression Diode Amperage Test Circuit Schematic
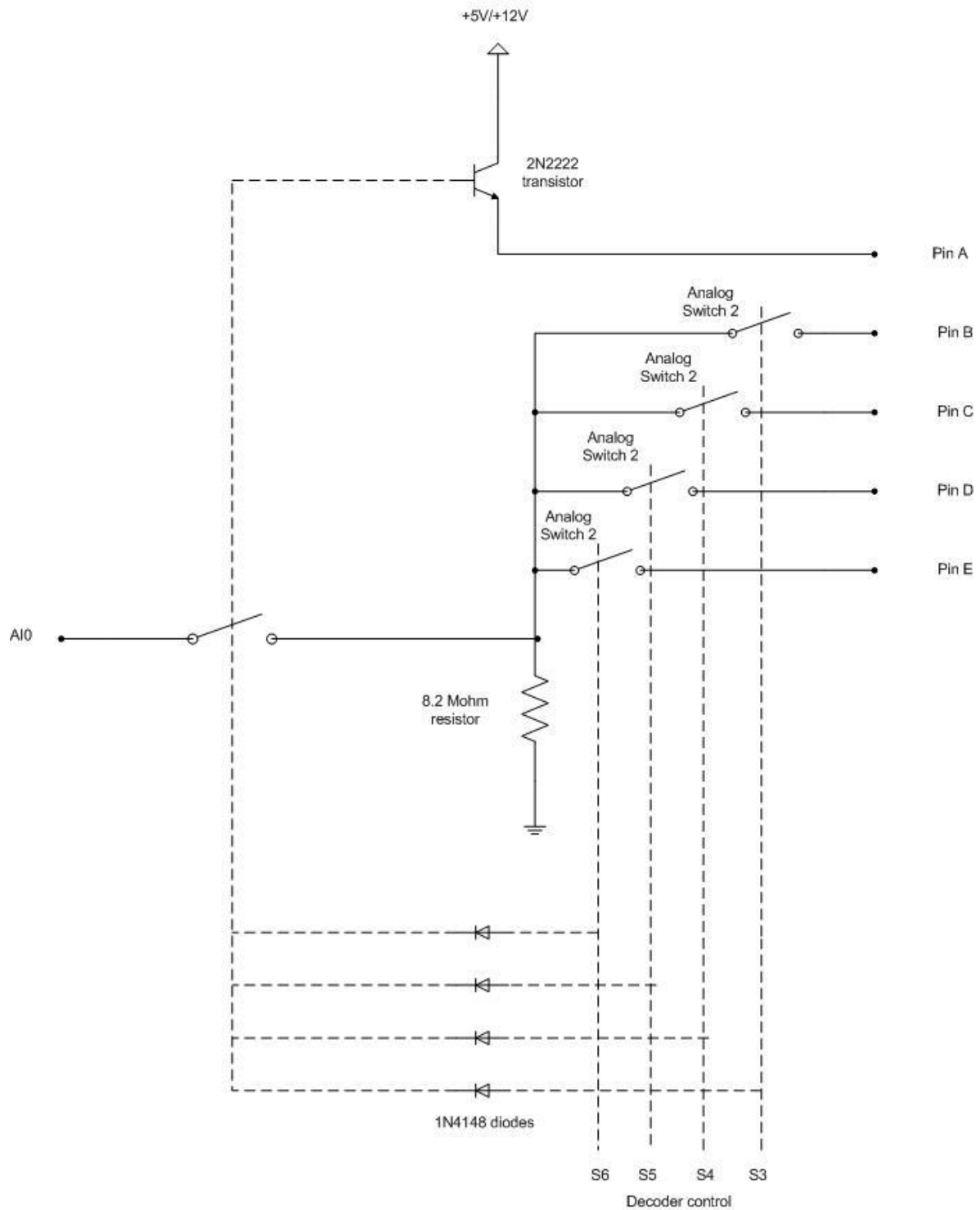

Coil Suppression Diode
Amperage Test

6.3.4. Coil Amperage/Resistance Test Circuit Schematic
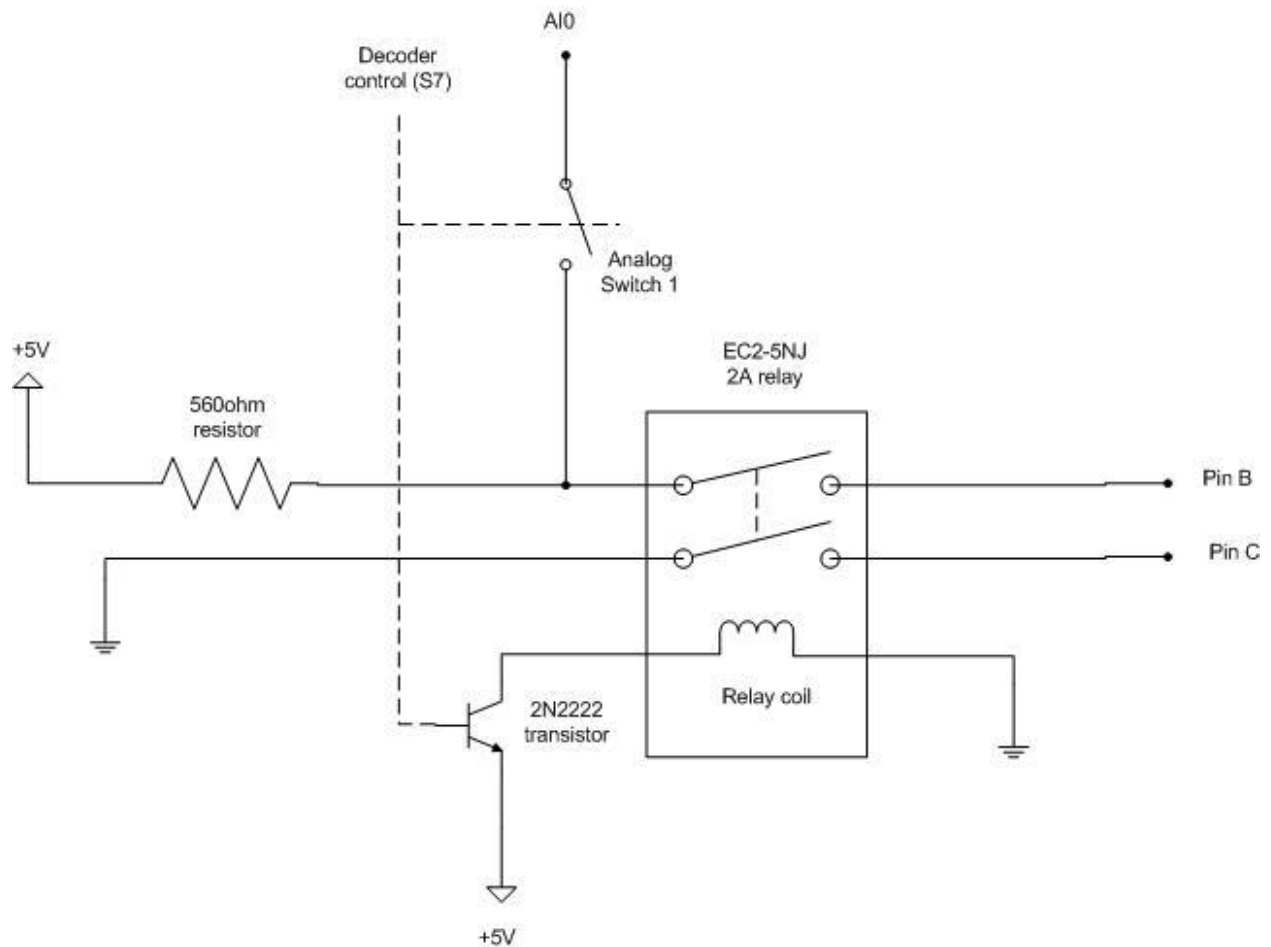
Coil Amperage and Resistance Test

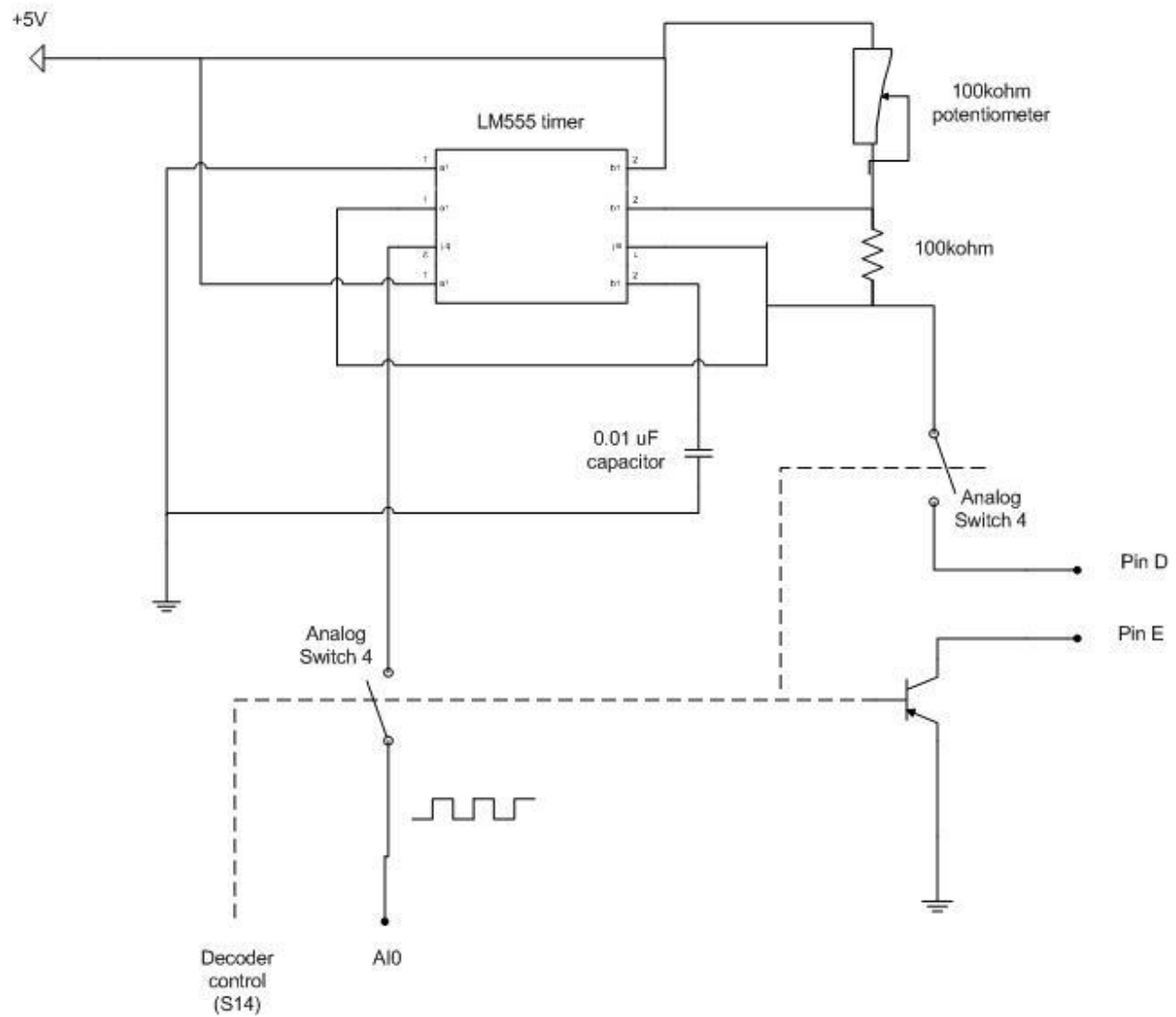## 6.3.5. Continuity Test Circuit Schematic

Continuity Tests

+5V/+12V

2N2222
transistor

Pin A

Analog
Switch 2

Pin B

Analog
Switch 2

Pin C

Analog
Switch 2

Pin D

Analog
Switch 2

Pin E

AI0

8.2 Mohm
resistor

1N4148 diodes

S6   S5   S4   S3

Decoder control

6.3.6. Resistance Test Circuit Schematic

B to C Resistance Test

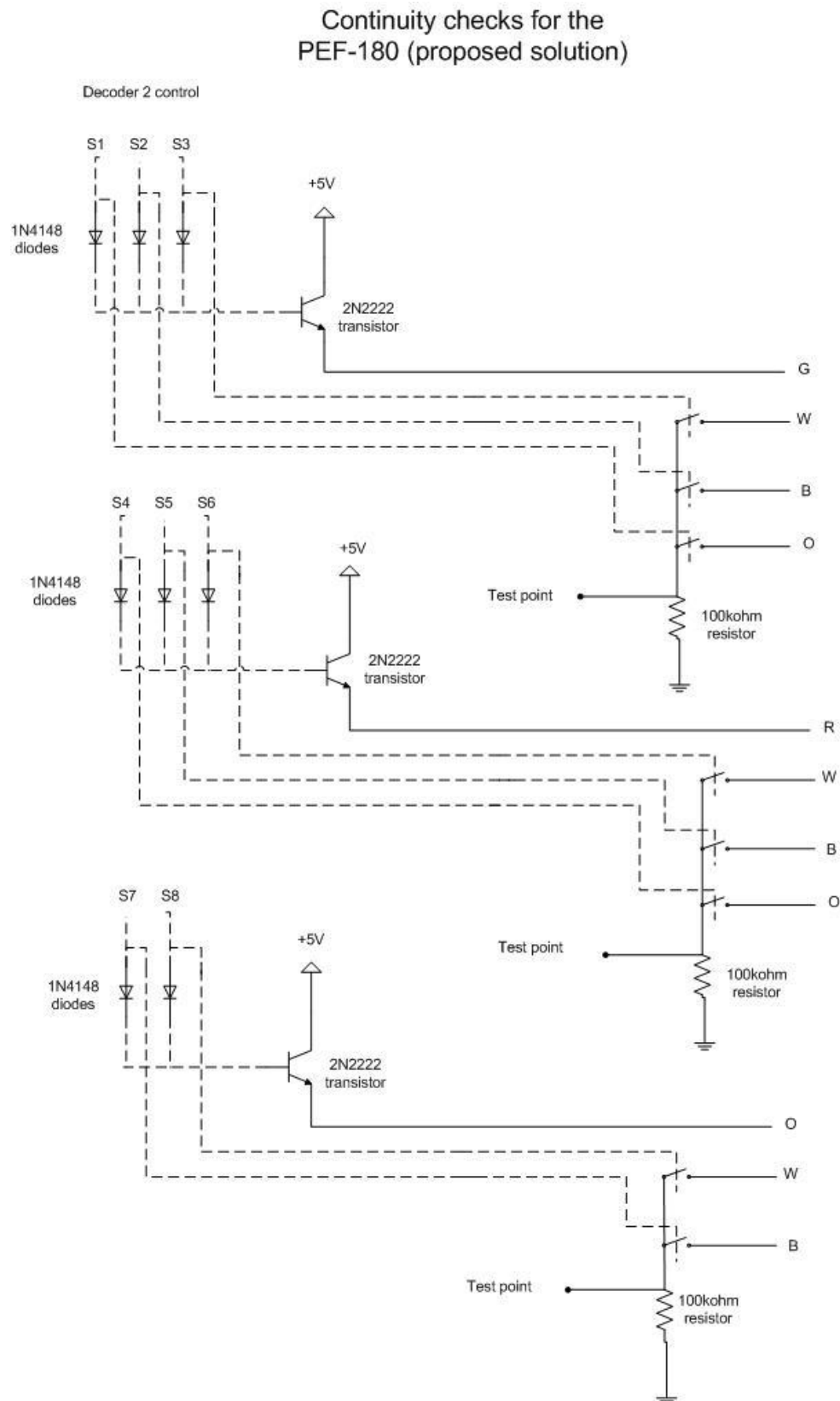## 6.3.7. Capacitance Test Circuit Schematic

22nF Capacitor Test
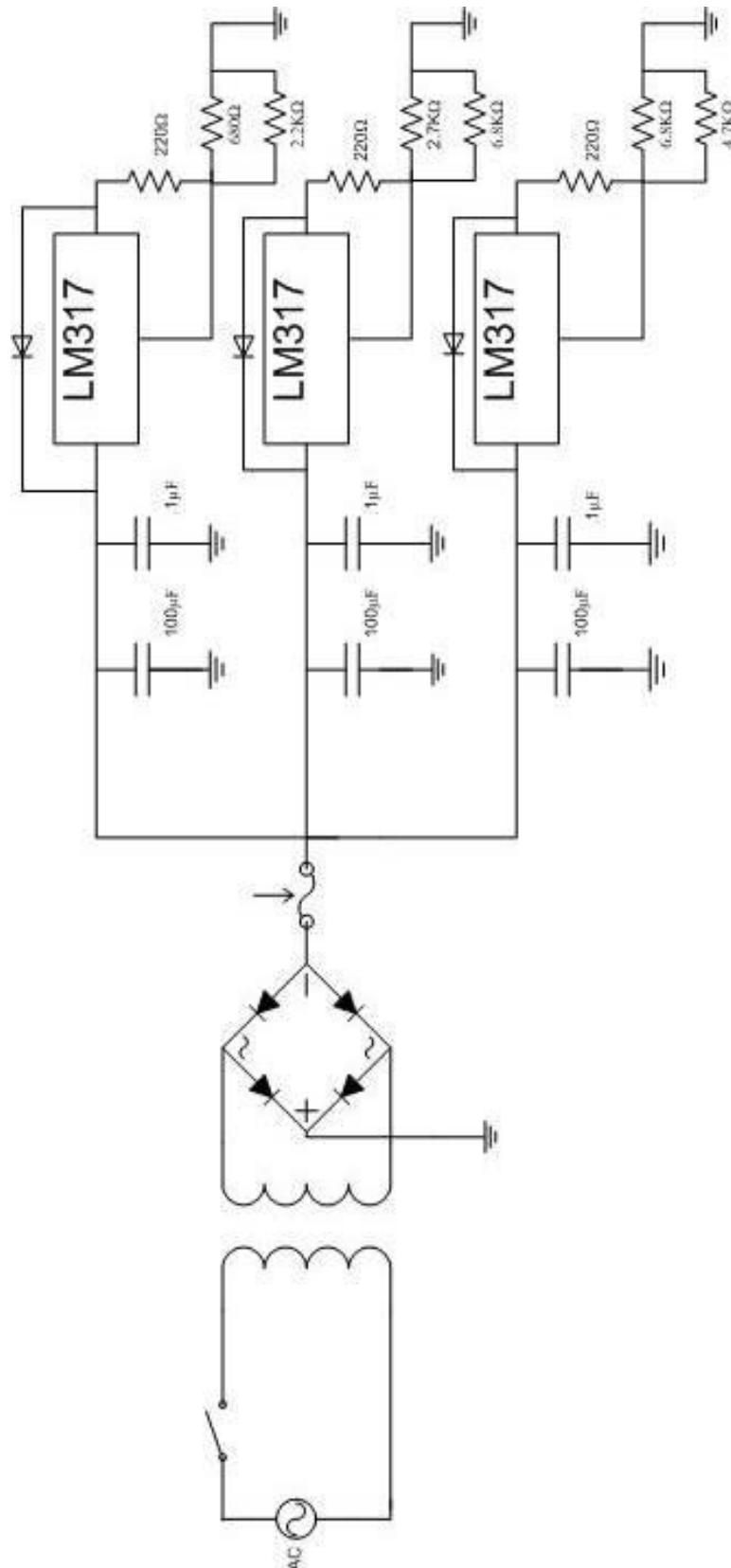
6.3.8. Test Addition Circuit Schematic

Adding a Test
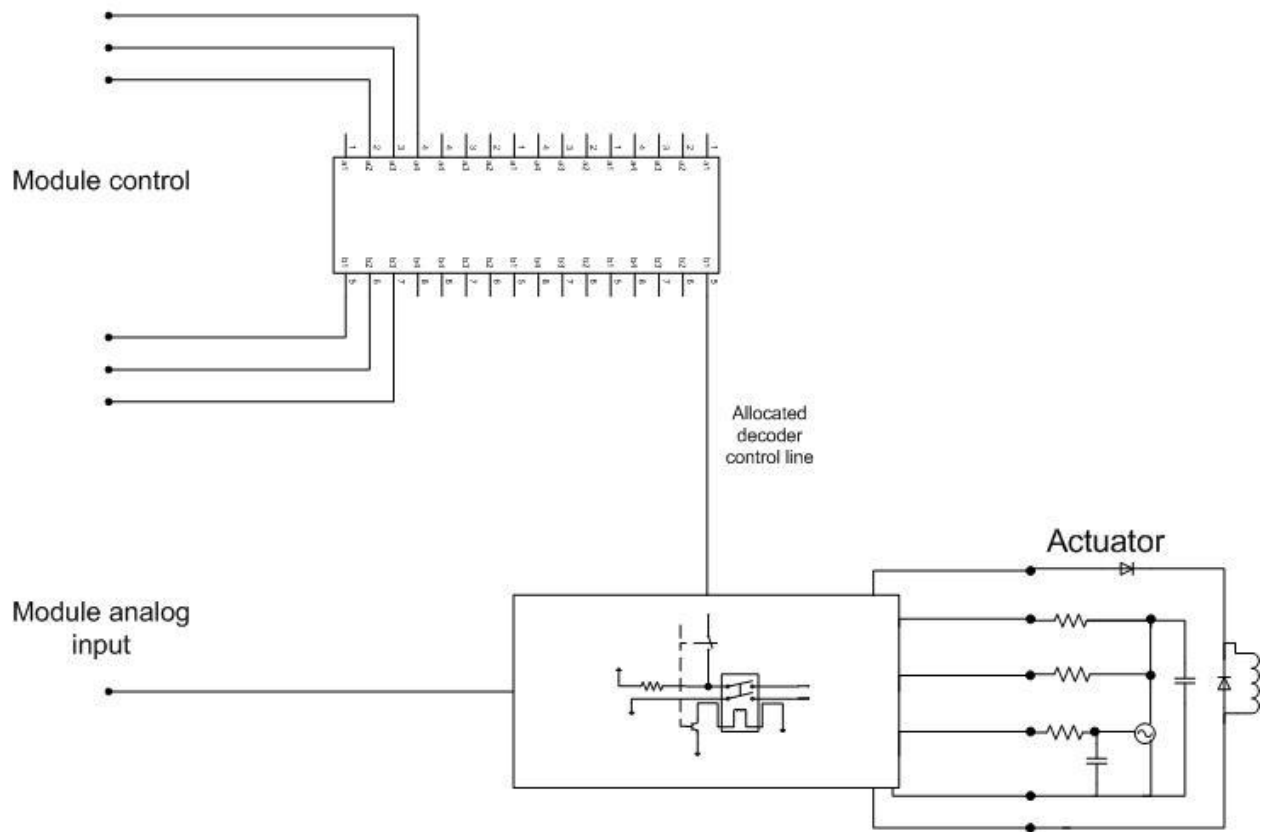
6.3.9. PEF-180 Continuity Test Solution Circuit Schematic

Continuity checks for the
PEF-180 (proposed solution)

6.3.10. Automated Actuator Inspection Device Power Supply Schematic

6.3.11. Automated Actuator Inspection Device Housing Draft

AAID Housing
Dimensions (Inches)
ECE 480 Team 6

6.3.12. Automated Actuator Inspection Device LabVIEW VI Hierarchy